

## Summary of Findings in Literature Reviewed

Some general trends in water quality parameters are evident in the literature as the river moves downstream from Keswick Reservoir to Verona. Water temperatures during the cold winter months tend to decrease with movement downstream (CDWR 1962). The opposite trend is found during the warmer months when temperatures and diurnal fluctuations in temperature increase in a downstream progression. Tributary streams for the most part also have higher temperatures and greater diurnal fluctuations than the main stem during warm periods.

Electrical conductivity, suspended sediments, dissolved solids, turbidity, color, and nutrient concentrations show a similar trend of increasing in a downstream progression. This trend, however, is interrupted with the inflow of low conductivity water from the Feather River (CDWR 1962, 1970, 1973, USGS 1974).

Periphyton, phytoplankton, and benthic macroinvertebrates show similar trends. Periphyton species richness (from Bend Bridge near Red Bluff to Knights Landing) increases as the river moves downstream. The biomass of periphyton, however, decreases in a downstream progression (CDWR 1962; Britton 1977; USGS 1977b). This trend is probably due to higher turbidity and sediment concentrations in the lower reaches of the river, which restricts light penetration (Britton 1977). Phytoplankton concentrations and diversity increase along a gradient from Bend Bridge to Knights Landing (CDWR 1962; USGS 1974, 1977b; Britton 1977). Species richness, density, and diversity (Shannon-Weaver Index) of benthic macroinvertebrates decrease in a downstream progression (CDWR 1962; USGS 1974; 1977b). This trend is probably due to the more suitable riffle habitat and better quality water in the upper reaches of the river. It is noteworthy that species richness and density of benthic macroinvertebrates increase again in the highly productive lower estuarine system of the river, which is below the area of this review (CDWR 1962).

In addition to downstream trends in water quality and biological parameters, certain predictable seasonal trends were evident in the literature and historical data. Water temperatures follow the predictable trend of increasing during warm periods and decreasing during cold periods. The seasonal range of temperatures, however, is much lower at Keswick Reservoir than downstream. This is due to controlled summer releases at Shasta Dam from the cool hypolimnion, and warmer-than-normal winter releases due to heat trapped in the reservoir during warm periods (Moffett 1949). Total dissolved solids and electrical conductivities of tributaries to the Sacramento River tend to increase during low-flow conditions (summer and early fall), but decrease with increased flows in the winter and spring (USGS 1974, and CDWR historical data). In the river proper, however, electrical conductivities are often highest during the winter and spring months, particularly in the upper reaches (CDWR historical data). Turbidities, suspended solids concentrations, and sediment

transport are very responsive to, and increase with, higher rainfall and flows (CDWR 1970, 1973; USGS 1972, 1974; U.C. Davis 1979).

Highest phytoplankton concentrations in the Sacramento River were observed in September (Britton 1977). This is predictable since low flows, increased temperatures, and decreased turbidities during this period of time are all conditions conducive to algal production. Benthic macroinvertebrates showed decreases in density from September to April (USGS 1977b). Declines were probably tied to increased flows (resulting in washout and increased spatial distribution of organisms) and spring emergence. The greater densities found in September may have resulted from the concentration of organisms due to lower flows and repopulation from the hatching of eggs into immature stages.

The U. S. Environmental Protection Agency's (USEPA) 1974 report to Congress identifies the Sacramento River as one of California's most difficult non-point source problem areas, with low level quality. The problem stems mainly from agriculture and is specifically related to high nutrient concentrations.

Several sources of water quality degradation for the Sacramento River are continually reviewed in the literature. The major sources include municipal wastes, industrial wastes (primarily food processing and lumber industries), agricultural drainage, and acid mine wastes (restricted to the upper Sacramento River) (CVRWPCB 1955; CDWR 1960, 1962, 1970; Brennan 1963; USBR 1981).

Conflicts in land use are also prevalent in the literature, primarily between agricultural and environmental concerns. Coordinated levee work to control flooding on the middle and lower Sacramento River began in the early 1900s. This work stemmed from severe flooding in the lower river basin due to hydraulic mining debris from the Feather and American Rivers, and uncoordinated construction of reclamation levees in the lower and middle reaches (CDFG 1982). Erosion had threatened the integrity of the levee system and a program of revetment construction was authorized in 1960. Early construction was on a least-cost basis and resulted in a serious loss of riparian vegetation which supplied important wildlife habitat (Mifkovic and Peterson 1975). A continual encroachment by agriculture and urban development is occurring on the Sacramento River flood plain. Between 1952 and 1977, native vegetation in the Sacramento River riparian zone from Redding to Colusa had decreased 14 percent, while agricultural use had increased 12 percent and urban use increased 3 percent (CDWR 1979b). Bank erosion threatens private lands (orchard, row crops, and homes) and is a major concern of property owners and public agencies. The effects of bank protection (riprap) on fish, wildlife, and native vegetation, however, are major concerns to environmental groups and agencies. The Department of Fish and Game (1982) recommended some alternatives to alleviate or reduce the impacts of bank protection. These recommendations include governmental procurement of the meander belt, better design criteria for bank protection, planning alternatives for

salmon spawning and rearing facilities, and additional studies to better understand the consequences of bank protection.

## Introduction

The purpose of this study was to collect and review available data and reports relating to water quality, aquatic biology (benthic invertebrates, plankton, and periphyton), and waste assimilation for the Sacramento River from Keswick Reservoir to Verona (below the confluence of the Sacramento and Feather Rivers).

An annotated bibliography of articles and information reviewed is presented in Appendices B and C. Three Sacramento River reaches (upper, upper-middle, and lower-middle) are discussed under separate headings. The upper reach extends from Keswick Dam (mile 302) to Red Bluff (mile 245), the upper-middle reach extends from Red Bluff to Colusa (mile 144), and the lower-middle reach extends from Colusa to Verona (mile 79). The mileage designations were determined from a reference point of Collinsville in the Delta (USACE 1980).

Major beneficial uses of the Sacramento River include municipal, industrial, and domestic water supply, irrigation, power generation, salinity control, navigation, fish propagation, flood control, disposal of wastes, and recreation (CVRWPCB 1955; CDWR 1962).

The Sacramento River and many of its major tributaries are highly regulated systems. The river proper is impounded by Shasta Dam, Keswick Dam, and the Red Bluff Diversion Dam. Three major tributaries above Shasta Reservoir (which is beyond the scope of this review) are also impounded. The Pit River has a series of seven Pacific Gas and Electric (PG and E) dams, while the McCloud River has been impounded by P G and E to form McCloud Reservoir. In addition, the Sacramento River above Shasta Lake has been dammed by Box Canyon Dam near Mount Shasta City. Clear Creek, Stony Creek, and the Feather River are also regulated by reservoir systems. Clear Creek was impounded to form Whiskeytown Reservoir and is the system through which Trinity River water is diverted into the Sacramento River drainage. Stony Creek has three reservoirs including East Park, Stony Gorge, and Black Butte. The Feather River is regulated by Oroville Dam and a series of P G and E power generation dams on its north fork. While lower tributaries to the Sacramento River (i.e. American River, Cache Creek, and Putah Creek) are also regulated, they are below the area of investigation in this report.

The Sacramento River Basin has a drainage area of 26,960 square miles with 5,000 square miles making up the valley floor from Red Bluff to Suisun Bay (CVRWPCB 1955). The river flows through Recent sediments from Redding to the

Bay, with the exception of a small area of nonmarine sediments just north of Red Bluff. The major tributaries (i.e., Feather and American Rivers) originate in the Sierra Nevadas (Brennan 1963). Waters of the Sacramento River Basin are generally classified as calcium and magnesium bicarbonate in type (CDWR 1960; Brennan 1963). The upper reaches of Churn and Stillwater Creeks, however, were typed as magnesium-sodium bicarbonate, while Clear Creek was calcium sodium bicarbonate in type (CDWR 1960), and Colusa Basin Drain waters were sodium magnesium bicarbonate in type (date on file with CDWR).

The chemical quality of surface waters in the basin is directly related to the geology of their origins. Streams draining the crystalline formations north and east of the valley are low in dissolved solids and electrical conductivity (EC), while streams from the coastal sedimentary rocks are substantially higher in dissolved solids and EC (Brennan 1963). Historical data on file with the California Department of Water Resources (CDWR) support this observation.

### Upper Reach of Sacramento River

For the purpose of this review the upper reach of the Sacramento River extends from Keswick Reservoir (mile 302) to Red Bluff (mile 245) (Figure 1). The river flows through steep terrain near Keswick and rolling hills below Redding, in a well-defined channel with some rapids (CDWR 1962). The river falls approximately 200 to 250 feet in this 57-mile reach. At Red Bluff, the river enters the valley proper, making it a logical cutoff point for the upper reach.

Approximately 960,000 acre-feet of water is imported yearly from the Trinity River into this reach of the Sacramento River (USGS 1972). This imported water is carried via Spring Creek Tunnel and Clear Creek from Whiskeytown Reservoir to the Sacramento River. Spring Creek Tunnel water enters Keswick Reservoir by way of Spring Creek, while Clear Creek meets the Sacramento River between Redding and Anderson. Other tributary inflows of some significance include Cow, Bear, Battle, and Paynes Creeks from the east and Cottonwood Creek from the west. The only major irrigation diversion in the upper reach is the Anderson-Cottonwood Irrigation District Canal that starts in the City of Redding (mile 298.5).

### General Water Quality (Upper Reach)

Shasta Reservoir is a major controlling factor on water quality in the upper reach of the Sacramento River (Keswick to Red Bluff). Like many large hypolimnion release reservoirs, it has resulted in a depression of various physical and chemical regimes in its tailwaters.

Summer water temperatures in the upper river are substantially lower than prior to

construction of Shasta Dam. This is due to cool hypolimnion releases from the reservoir. Winter temperatures below Keswick, on the other hand, have been higher subsequent to Shasta Dam's construction. Heat stored in the reservoir water is influential in maintaining higher temperatures in the river long after climatic conditions would have normally cooled the water (Moffett 1949). The combined effects of heat trapped during cool months and deep water releases during warm months have effectively narrowed the seasonal range of temperatures in the upper reach of the Sacramento River. In addition, controlled releases from Shasta Dam have substantially depressed diurnal temperature fluctuations (Moffett 1949).

Winter and spring river temperatures are lowest and remain relatively constant from Keswick to Red Bluff, occasionally showing a slight decline in a downstream progression. Summer and fall temperatures in the same reach are substantially warmer (5-10°F) and increase in a downstream progression (CDWR data).

Upstream storage provided by Shasta Dam results in lowest values for suspended solids, turbidity, and color to be found in the river below Keswick (CDWR 1962, 1970). Data collected by CDWR in 1983 and 1984 indicate that turbidity values remain relatively constant, increasing slightly as the river flows from Keswick to Red Bluff. Turbidity spikes occur during major storm events with the largest inputs coming from major tributaries such as Cottonwood Creek and bank erosion. Lowest turbidity values in this reach of the river occur under low flow conditions during the late summer and early fall.

The hydrogen ion concentration (pH) in the upper reach ranged from 6.8 to 7.5 during 1983 and 1984 (CDWR data). The pH remains relatively constant, with a slight increase on some dates, as the river flows from Keswick to Red Bluff. Seasonal trends were not readily apparent in the historical data.

Electrical conductivities in the tributaries of the upper reach of the Sacramento River follow the classic pattern where conductivities are highest under low-flow conditions (i.e. late summer and early fall) and lowest during winter and spring high flows. The river itself, however, does not follow this pattern. Conductivities in the upper river show lowest values in the summer months while peaks occur during the winter (CDWR data 1960-69 and 1983-84). Once again, this appears to be a phenomenon stemming from the limnology of upstream storage. Vertical profiles collected in 1983-84 from Shasta Reservoir near the dam show highest electrical conductivities in the deeper waters to occur during the winter, while lowest values occur in the summer (CDWR data). Higher electrical conductivities in the winter are probably the result of increased mineralization from turbid tributary inflows. Lower conductivity values occur during the summer following settling of the mineral-containing sediments.

Electrical conductivities in the upper river tend to stay fairly constant or increase slightly as the river flows from Keswick to Red Bluff. Monthly data collected from ten

stations in this reach by CDWR in 1983-84 showed a range of electrical conductivities from 84 to 128  $\mu\text{mhos/cm}$ .

Nutrient values are generally lowest in the upper reach of the river (CDWR 1970, 1973; CDWR 1983-84 data) with the lowest values as indicated by total phosphorus occurring during the summer months. This may be due to the uptake of nutrients by periphyton during the summer months. Total phosphorus concentrations never exceeded 0.05 mg/L (CDWR 1983-84 data) for this reach of the river.

Dissolved oxygen concentrations in the upper river historically are high, ranging from 10 to 11 mg/L near Redding with percent saturations over 95 (CDWR 1962). Data collected by CDWR in 1983 and 1984 are similar with concentrations ranging between 9.5 and 12.0 mg/L. Therefore, it appears that organic inputs from sewage treatment (i.e. Redding, Anderson, and Red Bluff) as well as major industries (i.e. Simpson Lee Paper Products and Diamond International Lumber) may not have substantially degraded water quality in the river system. However, current information on diurnal dissolved oxygen cycles was not found.

### Acid Mine Drainage

One of the major sources of water quality degradation in this reach of river stems from heavy metal pollution resulting from acid mine drainage into the system above Keswick Dam. The first known study on acid drainage in the area was conducted in 1939 prior to completion of Shasta Dam. Numerous studies by private and governmental agencies have been conducted since. Major sources, impacts, and potential abatement procedures have been identified. Specific sources (mines, tailings, etc.) of acid mine drainage as well as a historical overview of mining in the Shasta-Keswick area is presented by Lydon and O'Brien (1974), U. S. Geological Survey (1977a, 1978a), and Prokopovich (1981). Drinking water standards in the river at Redding have also occasionally been exceeded for iron and manganese during storm periods (CDWR 1962).

Heavy metals and acid are released by oxidation in the presence of oxygen and water of massive fine-grained sulfide ores in abandoned surface mines, subsurface mines and tailings. The resultant acidic solution causes further dissolution of heavy metals from the ores. Extremely acid waters result with high concentrations of iron, copper, zinc, cadmium, aluminum, and other heavy metals (CDFG 1953; Nordstrom and Stoner 1977; Nordstrom 1977; USGS 1977a, 1978a).

Major tributary sources of heavy metals in the Shasta-Keswick area were identified by USGS (1977a, 1978a). Four creeks (Little Backbone, West Squaw, Horse, and Town) carried high concentrations of dissolved metals into Shasta Lake, while Spring and Flat Creeks contributed high metal concentrations to Keswick. The Pit River was

found to contribute a substantial load of metals to Shasta Lake, but this was due to high flows rather than high metal concentrations. Spring Creek was found to contribute 50 percent of the metal loads in the area and is the largest single source.

Seasonal changes in heavy metal concentrations are evident in streams affected by acid mine drainage. Under low-flow conditions the concentrations of dissolved metals are highest. The total load of discharged metals, however, is highest during periods of peak runoff (Leeds, Hill, and Jewett 1957; CDWR 1969; CDFG 1974). During periods of low flow, toxic sediments accumulate in streambeds (USFWS 1959) and heavy metals may enter storage in mine dumps, underground fracture systems, or streambeds (CDWR 1983b). During the first major rains, these stored metals may be discharged into the river system.

Prior to the construction of Shasta Reservoir, increased runoff and high flows in the river proper were substantial enough to adequately dilute the acid mine runoff. No toxic effects on the river fauna and flora were realized. With the advent of controlled releases from Shasta Dam, much higher concentrations of metallic salts in the river occurred during periods of high tributary runoff, resulting in many fish kills (Leeds, Hill, and Jewett 1957). Numerous fish kills that are a direct result of acid mine drainage have been documented for Shasta Reservoir, Keswick Reservoir, and the Sacramento River below Keswick (CDFG 1953, 1974; USFWS 1959; Benoit et al. 1967; USGS 1977a; Prokopovich 1981).

Fish are not the only organisms adversely affected by acid mine drainage. The benthic flora and fauna (bottom-dwelling plants and animals), which provide a major food source for fish, are also affected. Spring Creek itself has been described as a biological desert (Prokopovich 1965). In 1955 and 1956, an analysis of periphyton in Keswick Reservoir, its tributaries, and the river below Keswick Dam was made with diatometers (ANS 1956; Benoit et al. 1967). Diatom growth in Spring Creek and Flat Creek was either nonexistent or severely reduced as compared to other tributaries without acid mine drainage. During low-flow conditions, some imbalance in diatom growth was noted in Keswick Reservoir at the mouth of Flat Creek and from the mouth of Spring Creek to Lake Redding. During the high-flow period, diatom degradation was even more apparent in the river. Diatom degradation was found even when chemical data did not show problems.

Two tributaries to Shasta Lake (West Squaw Creek and Little Backbone Creek) with acid mine drainage were analyzed for benthic macroinvertebrates in 1975 (USGS 1978a). West Squaw Creek benthic communities were of poor biological quality with low species richness, low densities of organisms, and very low Shannon-Weaver diversity indices ( $<1.0$ ). Little Backbone Creek, in the area affected by mine drainage, showed a similar trend. At two stations above the influence of mine wastes, the benthic communities showed healthy species richness, densities, and diversities.

In 1980, Johnson (1981) analyzed the benthic macroinvertebrate community of Keswick Reservoir from above the confluence of Spring Creek to just over one mile below its mouth. The density, species richness, biomass, and diversity of organisms decreased dramatically from above to below the mouth of Spring Creek. Conversely, sediment concentrations of copper, zinc, and iron, as well as percent ash, increased below the confluence.

Anadromous fish that migrate beyond Cottonwood Creek run the risk of acid mine poisoning from the Spring Creek drainage (Finlayson and Wilson 1979). Consequently, heavy metal toxicity bioassays have been conducted on king salmon and trout in the area since the 1950s. The bulk of the work, however, was conducted in the late 1970s and early 1980s. Several factors enter into the toxicity of heavy metals to fish, including other water quality parameters (i.e. hardness), the additive or synergistic effects of some metals with one another, and the differences in toxicity to different life history stages of fish.

Control and abatement of acid mine drainage in the Shasta-Keswick area has been the subject of several reports since the late 1950s. Currently, the U. S. Bureau of Reclamation (USBR) is evaluating various long-term water management solutions for controlling toxic mine drainage, while the Central Valley Regional Water Quality Control Board is concentrating its efforts to control the pollution at its source (USBR 1982). Proposed control and abatement procedures to reduce acid mine drainage have included removal of mine tailings or covering them with an impervious blanket, interception of pollutants by construction of reservoirs, chemical treatment to neutralize the effluent, diversion of surface waters around mines and tailings, sealing of mines, construction of copper precipitation facilities, electrochemical extraction of metals, maintenance of mines to prevent ponding of water and long-term contact with the ores, and cribbing, crowning, grading, terracing, and berming of tailings to reduce erosion (Leeds, Hill, and Jewett 1957; CDWR 1969; Nordstrom and Stoner 1977; USGS 1978a; AEC 1983).

In 1958 a copper precipitation plant was constructed and updated in the Spring Creek drainage. In 1964 the plant removed 50 tons of copper (Prokopovich 1965). Nordstrom and Stoner (1977) stated that although the copper recovery plant may remove 98 percent of the copper entering from the Richmond and Hornet Mines, high metal concentrations still are allowed to discharge from the plant during heavy runoff periods.

The Spring Creek Debris Dam, with a 5,800 acre-foot capacity, was completed in 1963. It was felt through controlled releases from Spring Creek, Whiskeytown Reservoir into Spring Creek (near the Spring Creek Tunnel), and Shasta Dam that acid mine drainage could be adequately diluted. Therefore, Spring Creek water would be rendered harmless to fish in the river (Prokopovich 1965). The problem, however, still exists today. When runoff exceeds the capacity of Spring Creek Debris Dam, spills

occur. Adequate dilution releases can not be made from Shasta Dam because of the potential for flooding downstream (USBR 1982). The Bureau is looking at the possibilities of enlarging Spring Creek Debris Dam and diverting nontoxic Spring Creek flows directly into the river in an attempt to alleviate the problem. Safe dilution factors for Spring Creek water were determined for complete and instantaneous mixing in Keswick Reservoir. Occasionally, when these dilution factors for fish are being met, metal concentrations in the river below Keswick still exceed safe levels (Kenneth Iceman, CH2M Hill, pers. coma.). This may indicate that Spring Creek does not fully mix in Keswick Reservoir prior to reaching Keswick Dam.

Probably the first attempt to alleviate acid mine drainage into the Sacramento River was a mine sealing program on Little Backbone Creek in 1943. The program was considered ineffective since all the seals were broken. It was not known, however, if the mines were properly sealed originally (CDFG 1953). In December 1981, a seal was placed in the main Mammoth Mine adit. Preliminary indications were that the seal had effectively reduced the flow of heavy metals into Little Backbone Creek. The water had backed up behind the seal, however, and was exiting the Friday-Lowden Portal in Shoemaker Gulch (one drainage away), where heavy metal concentrations of the effluent had greatly increased.

In June 1980, a project was built to divert surface water around a slope of the Balaklala Mine in the West Squaw Creek drainage (AEC 1983). When operational, the diversion effectively reduced the flow of effluent from the mine. The actual metal load was not reduced, since the metal concentration of the effluent had increased. In November 1980 a concrete air seal was placed in the Weil Portal of the Balaklala Mine. When no improvement was observed in the effluent, a total hydraulic seal was constructed in March 1982. The resultant copper and zinc concentrations in West Squaw Creek were reduced 90 percent.

Further research has been suggested by the U. S. Geological Survey (USGS 1977a) to include studying the effects of complexation, sorption, ionic strength, hardness, and solubility on heavy metal toxicity, the chronic toxicity from metal buildup in sediments, and the potential for bioconcentration of metals. In addition, there is a need to determine the extent of mixing of Spring Creek water in Keswick Reservoir so that safe dilution release schedules can be updated.

### Biological Water Quality (Upper Reach)

Historically, bacteriological quality of the upper river was adversely affected by non-disinfected sewage from the cities of Redding and Red Bluff and industrial discharges from pulp mills, paper mills, and a slaughterhouse (CDWR 1962). Coliform bacteria concentrations were highest in the river immediately below sewage outfalls and during periods of low flow. No current bacteriological data were reviewed and there is a need to find such information. It seems likely that bacteriological quality

in the upper river has improved. The cities of Redding, Anderson, and Red Bluff now possess secondary sewage treatment facilities. In addition, the slaughterhouse in Red Bluff is no longer in operation. However, there is still the potential for problems since increased development in the upper valley is taking place.

Plankton studies were conducted on the Sacramento River by CDWR in 1960-61 (CDWR 1962). The lowest concentrations of plankton were found in the upper river from Keswick to Bend Bridge. Monthly samples were collected from four stations in this reach. Plankton concentrations increased gradually in a downstream progression. Diatoms were the dominant group in all cases in the upper river, while zooplankton concentrations were small and insignificant (less than one percent). Seasonal trends were quite evident. Plankton concentrations were lowest in the winter months (December through April) and peaked in August and September. Temperature was the most important controlling factor. Streamflow and biological oxygen demand (BOD) were also of some importance. There was a direct relationship with plankton concentrations and temperature and BOD, while there was an inverse relationship with streamflow.

A similar study was conducted on Sacramento River plankton in 1972 and 1973 (USGS 1974; Britton 1977). Once again, phytoplankton concentrations as well as species richness were lowest in the upper river and diatoms were still the dominant organisms. Species composition was quite similar between the studies; though fewer genera of plankters and lower concentrations were present in 1972 and 1973. In a September 1973 USGS study at Bend Bridge, phytoplankton concentrations were dominated by blue-green algae (USGS 1976). Blue-green algae usually dominate areas experiencing eutrophication. Further phytoplankton monitoring on a periodic basis may be of some value to detect any cultural eutrophication of the river system.

The periphyton community was also studied by CDWR in 1960 and 1961 on a qualitative basis (CDWR 1962). The USGS performed a more quantitative analysis of periphyton in 1972 and 1973 (USGS 1974; Britton 1977). Twenty-seven genera of attached algae were identified by DWR. These genera were represented by greens, blue-greens, reds, yellow-greens, and diatoms. The USGS found the periphyton community to be dominated by diatoms. Species richness was lowest at the stations in the upper river, but periphyton biomass was highest. The high biomass of attached algae in the upper river was attributed to the low turbidity as compared to lower stations.

Large growths of aquatic moss have been observed in the upper river. These growths are mainly restricted to riffle areas and are very prominent during summer and early fall (CDWR 1962). These plants appear to go dormant during the winter. The moss was identified as *Fissidens* sp. in 1960 and 1961 (CDWR 1962), while in 1969 it was identified as *Fontinalis* sp. (IPC 1970). Sanford et al. (1974) from University of California, Davis identified the growths as *Hygrohypnum ochraceum*.

Three factors were identified of special significance to the growth of this moss: temperature, current velocity, and CO<sub>2</sub> concentrations. Sanford et al. (1974) found no evidence to suggest that the growths were caused by industrial enrichment.

Benthic macroinvertebrates have been extensively studied in the upper reach of the Sacramento River. In 1960 and 1961, 39 benthic samples were collected with a Surber sampler from three locations ranging from Mill Creek to Anderson (CDWR 1962). Similarly, USGS in 1972 and 1973 collected monthly samples from two stations (below Red Bluff and at Bend Bridge), but used Peterson and Ponar dredges (USGS 1974, 1977b). In both studies, species richness, diversity, density, and biomass were higher in the upper river than the lower reaches. Benthic macroinvertebrate densities generally increased from May through September and decreased from September through April. The benthic community was characterized by species that inhabit clean, fast-moving water. The major groups includes caddisflies, mayflies, stoneflies, true flies, and oligochaetes, with dipterans in the family Chironomidae dominating.

Benthic macroinvertebrates have been studied on a near yearly basis from above Red Bluff to Anderson since 1962. This work, funded in the first seven years by Kimberly Clark Corporation and then by Simpson Lee Paper Company since 1972, was designed to determine the impacts of the paper mill effluent on the Sacramento River. The work has been conducted by the Institute of Paper Chemistry (IPC) from Appleton, Wisconsin, during October in the study years. This is a unique study in that it allows the determination of long-term changes that have taken place in the upper Sacramento River over the past 20 years.

The IPC found true flies to be represented by more genera, but caddisflies were numerically dominant. Zanella (1982) describes the benthic community as moderately diverse and moderately productive. The relative community composition has remained consistent from station to station. There was some fluctuation in total species richness which was considered a function of habitat differences between riffles. The only major change in community structure has been a shift in dominance between two caddisfly species. *Brachycentrus americanus* was numerically dominant during the 1960s and early 1970s. From 1975 through 1978, the density of *Hydropsyche* sp. increased markedly, while *Brachycentrus* populations fell off to near zero. Zanella (1982) suggests that this shift in dominance is related to a selective susceptibility to the toxicity of heavy metals (zinc, copper, and cadmium). The Institute of Paper Chemistry (1978), however, points out that this shift in dominance occurred during the 1976-77 California drought. During the drought, epilimnion releases were being made from Shasta Dam. This resulted in reduced flows, increased temperatures, and increased concentrations of plankton in the river. It seems likely that *Hydropsyche* was favored under these conditions and therefore replaced *Brachycentrus* as the dominant species. During the 1980 study, a slight reversal in

the trend was noted (IPC 1981). *Brachycentrus* populations increased while *Hydropsyche* numbers declined. Further research needed to determine if this trend continues.

There appears to have been an overall enrichment of the river over the course of the macroinvertebrate study. A steady increase in average density of organisms has occurred with periodic, somewhat cyclic, setbacks. There was a five-fold increase in the average density from 1962 to 1978 (400 to 1,900 individuals per square foot, respectively). Cultural eutrophication caused by nutrient loading from municipal, industrial, and agricultural sources is the suspected cause (IPC 1979).

The UOC study provides an excellent data base for the upper Sacramento River. Continuation of the study would be valuable in ascertaining future trends and impacts on the Sacramento River.

### Upper-Middle Reach of Sacramento River

The upper-middle reach of the Sacramento River, in this review, flows from Red Bluff (mile 245) to Colusa (mile 144) (Figure 2). At Red Bluff the river is impounded behind the Red Bluff Diversion Dam (mile 243). From the diversion dam the river enters the valley proper and flows in a sinuous pattern with braiding and anabranching tendencies to Colusa (CDFG 1982). This flow pattern results from a dynamic river system and is characterized by the formation of numerous ox-bow lakes and islands (Bryan 1923). At Colusa the river becomes virtually canalized, with setback levees closely bordering either side of the river. The levee system actually begins further upstream (mile 184 on the west side and mile 176 on the east side), but is set back far enough that it does not substantially influence the course of the river except under flood conditions.

The upper-middle Sacramento River flows mostly through Recent alluvium and has formed a flood plain that ranges from one to five miles in width (Bryan 1923; Brennan 1963). The gradient decreases from about 2.5 feet/mile at Red Bluff to 1.3 feet/mile near Colusa. A regular riffle-pool sequence is evident in unaltered areas, but is less apparent in the river below Princeton. The river bed is essentially gravel and cobble in the upper portions, with gravel becoming less apparent below the confluence of Stony Creek (mile 190). Near Colusa, the river bed is predominantly coarse sand with gravel occurring in crossover areas (CDFG 1982).

Tributary inflows of some significance in the upper-middle reach of the river include Antelope, Mill, Deer, and Big Chico Creeks from the east and Elder, Thomes, and Stony Creeks from the west. Agricultural diversions are common in this reach of the river. Some of the major diversions include the Corning Canal, Tehama-Colusa Canal, Glenn-Colusa Canal, Provident Irrigation District Canal, and River Branch

Canal. In addition, several smaller diversions by private farming interests are present in this reach (Robert McGill, CDWR, pers. comm.).

Land-use practices have changed dramatically in the 30-year period from 1952 to 1982. From Redding to Colusa, more than 10,000 acres of riparian vegetation has been lost, while orchard planting has increased by 16,000 acres within a narrow 72,000-acre corridor along the river (CDWR 1983a). A 1977 reconnaissance showed that 34 miles of active riverbank erosion was occurring from Red Bluff to Colusa (CDWR 1979b). Since there have been large monetary investments in the development of urban and agricultural lands along the river, bank erosion and bank protection are of major concern to landowners. By 1979, 26 miles of riprap had been emplaced by the Army Corps of Engineers along the 100-mile stretch of river from Red Bluff to Colusa. Bank protection was confined to the outside bends with high value development.

The California Department of Water Resources (1979a) found that 912 acres of prime high terrace soil were lost to bank erosion between 1972 and 1977 from Redding to Colusa. However, further studies showed that there had been no overall loss of these prime high terrace soils (CDWR 1983a). Natural soil building processes had actually created an equal or slightly greater amount of these prime soils than were lost to erosion.

Environmental interests are concerned with the impact of bank protection on the river and its riparian habitat. They tend to favor the purchase of actively eroding lands and allowing the river to meander. By 1983, 2,100 acres of riparian lands had been purchased and protected along the river.

An evaluation of the impacts of river bank erosion and protection was initiated in 1976 by the Corps of Engineers. In 1980, the California Department of Fish and Game (under contract to the Corps of Engineers) began a study to evaluate the impacts of bank protection on fish populations, to evaluate alternative methods of bank protection, to propose mitigation measures, and to develop future studies (CDFG 1982). Some of the major findings include: a statistically significant decline in the number of chinook salmon using riprap versus cut-bank areas; maintenance of spawning areas from Or&d Bend to Red Bluff may be a result of gravel recruitment due to lateral movement of the river into cut-banks; and survival of salmon fry would be reduced if current methods of bank stabilization are employed. Several recommendations for project design and additional studies were made in the 1982 CDFG study. Recommendations for project design included: top priority being given to non-structural alternatives, i.e., purchasing portions of the meander belt from Red Bluff for Chico Landing; using flatter slopes and smaller substrate for bank protection; and providing alternatives for spawning and rearing facilities that will support the impacted salmon runs. Additional recommended studies included: an inventory of spawning areas between Red Bluff and Chico Landing, development of a sediment

budget in the same reach, estimation of gravel recruitment through lateral migration of the river, assessment of morphological changes in the river that will result from bank stabilization, assess fisheries impacts below Or&d Bend, and initiate annual photographic inventories of spawning locations.

The Corps of Engineers in 1983 had not accepted the California Department of Fish and Game's findings. The Corps concluded that gravel recruitment from lateral movement of the river was insignificant. In addition, the Corps found through a 1981 sediment budget that bank erosion is a major source of sediment deposition downstream in the river. Therefore, it was felt further bank protection was warranted.

### General Water Quality (Upper-Middle Reach)

Winter water temperatures in this reach generally range from 45 to 50°F (CDWR data). According to CDWR (1962), winter temperatures in the river decline in a downstream progression. Current data collected during the winter of 1983-84 suggest that winter water temperatures between Red Bluff and Colusa stay fairly constant. Only slight temperature increases or decreases were noted in this reach as compared to the upper reach from Keswick to Red Bluff. However, the current data were collected over a two-day period each month and may not represent the true temperature progression as the river moves downstream. Current temperature recorder data had not been evaluated at the time of this report. These data will be more valuable in determining temperature trends in the Sacramento River.

Water temperatures in this reach during the rest of the year are higher than those in the upper reach and continue to increase as the river flows from Red Bluff to Colusa. The most dramatic increases in temperatures predictably occur during warm periods with low flow (late summer and early fall). In addition, seasonal and diurnal fluctuations of water temperatures in this reach are greater than the upper reach. This is largely due to the river moving towards equilibrium with atmospheric conditions as it flows further from Shasta Reservoir. Monthly water temperatures obtained with hand-held thermometers in the upper reach ranged from 47 F in February at Keswick to 58°F in July and August at Red Bluff, while the upper-middle reach ranged from 45°F in February at Tehama to 67 F in August at Butte City.

Suspended solids, turbidity, and color have been found to increase in a downstream progression (CDWR 1962, 1970, 1973). Current data lend support to this finding. However, during late summer and early fall, when turbidities are lowest, the trend is far less evident. Turbidity values are highest during the winter and early spring, due to tributary runoff and bank erosion from higher flows (CDWR 1970, 1973). Seasonal fluctuations in turbidity are greater in the upper-middle reach than in the upper reach. Turbidity ranged from 2.0 to nearly 10.0 FTUs in the upper reach, while values ranged from less than 2.0 to 28.0 FTUs in the upper-middle reach during

1983 and 1984. Some of the highest suspended solids values ever observed were found early in the winter of 1978. Some values showed a five-fold increase over historic data. This was largely due to heavy accumulations of sediments that occurred during the drought years of 1976 and 1977 (CDWR 1979a). This information demonstrates the value of water quality data collected during the drought years. It gives us an idea of worst case' conditions that can occur in the quality of Sacramento River water. An extensive review of this type of information would be invaluable in making future planning decisions with respect to the Sacramento River.

The mean pH of the river was found to be 7.3 (CDWR 1962). Data collected in 1983 and 1984 show that pH ranges from 6.8 to 7.6 in the upper and upper-middle reaches. It appears that the pH of the upper-middle reach is slightly greater than the upper reach, particularly during late summer and early fall.

Electrical conductivity (EC) continues to increase in a downstream progression in this reach. Values are nearly always higher in this reach than in the upper reach (CDWR data). Current data collected by CDWR's Northern District show values in the upper reach ranging from 84 to 140  $\mu\text{mhos/cm}$ , while conductivities in the upper-middle reach range from 95 to 161  $\mu\text{mhos/cm}$ .

Normally, lowest ECs in the river occur during the summer, while highest values occur in the winter (current and historic data). As mentioned in the previous section on the upper Sacramento River, this seasonal difference in ECs appears to be a phenomenon stemming from the limnology and operation of Shasta Reservoir. However, hydrologic factors operating in various years can alter this pattern. In 1960-61, EC was lowest during the spring due to dilution from snowmelt runoff (CDWR 1962). In 1970, lowest values in the river occurred during a series of January storms that caused excessive flooding, which resulted in dilution of mineral loads.

Total nutrient values tend to increase during the winter and in a downstream direction (CDWR 1970, 1973). Current data support these findings. Total phosphorus values were nearly always higher in the upper-middle reach than the upper reach.

### Biological Water Quality (Upper-Middle Reach)

Phytoplankton, periphyton, and benthic macroinvertebrate studies were conducted on the Sacramento River in 1960 and 1961 (CDWR 1962) and 1972 and 1973 (USGS 1974; Britton 1977). In both studies, phytoplankton concentrations and diversity continued to increase as the river moved downstream. Trends in species composition, dominance, temporal distribution, and controlling factors were the same as in the upper reach. Periphyton biomass continued to decrease, while species richness increased as the river progressed downstream. Other findings with the periphyton community were similar to the upper reach. Macroinvertebrate density and

diversity continued to decrease in this reach as compared to the upper reach. Oligochaete worms, chironomid flies, and clams became more prominent in the lower portion of this reach, while the upper portion was still characterized by species that inhabit clean, fast-moving water. Seasonal trends of the benthic community are similar to the upper reach.

The California Department of Fish and Game conducted a study comparing drifting insects at riprap and cut-bank areas of the Sacramento River, between Red Bluff (at the diversion dam, mile 241) and Chico Landing (mile 194)(CDFG 1982). Drifting organisms were dominated by chironomids (midge flies), baetids (mayflies), and terrestrial aphids at two paired upstream sites, while no single family was consistently more abundant at the lower paired site (near Chico Landing). No statistical differences in total quantity of organisms between riprap and cut-bank areas were found. However, baetid mayflies were significantly more numerous in cut-bank areas.

### Lower-Middle Reach of Sacramento River

The lower-middle reach, which is the lowest section of the Sacramento River to be covered in this review, flows from Colusa (mile 144) to Verona (mile 79) (Figure 3). This section of river is strongly influenced by historical flood control and land reclamation projects. The river flows through deep, wide alluvial fill. However, it has been virtually canalized with a rock-lined levee system that closely borders either side of the river. The pool-riffle sequence that was present above Princeton (mile 164) is no longer evident. The river gradient and velocity of flow have declined, resulting in bottom substrate primarily composed of sand, silt, and clay.

The Colusa Basin, which lies to the west of the river, is primarily a rice farming area due to poor quality soils (texture and high alkalinity) (CDWR 1964). The Colusa Basin Drain (CBD) conveys flood runoff and irrigation return flows from about one million acres of watershed. The CBD is one of the two largest sources of agricultural return flows to the Sacramento River, and discharges into the river near Knights Landing (mile 90)(U.C. Davis 1980a).

Immediately east of the river, from Colusa to Butte Slough (mile 138) lies the lower Butte Creek Basin. This is a low area that is subject to extensive flooding during high flow periods. Floodflows from the Sacramento River overflow into the Butte Basin via the Moulton Weir (mile 156) and the Colusa Weir (mile 146).

From the Butte Slough Outfall (mile 138) to the Sutter Bypass outfall (miles 80 to 84) large tracts of land (Reclamation Districts 70, 1500 and 1660) were reclaimed for agricultural purposes in the late 1800s and early 1900s. Directly east of this reclaimed land is the Sutter Bypass system, which was constructed in the early 1920s as a key element of the Sacramento River Flood Control Project. The Sutter Bypass is

a channel contained between levees set approximately one mile apart. High floodflows are diverted from the Sacramento River to the bypass via Tisdale Weir (mile 119) and the Butte Basin. However, enough flow is left to scour the main channel of the river. Prior to construction, the Sutter Bypass was a natural overflow area for floodwaters from the Butte Basin and the Sacramento, Feather, Yuba, and Bear Rivers (CDWR 1976).

During low-flow periods, two canals on either side within the Sutter Bypass are used for irrigation purposes. These canals are actually borrow pits, from which material was excavated in construction of the levee system. Most of the irrigation water is drainage from water districts north of the Sutter Buttes (i.e. Butte Basin). On occasions when water supplies have been low, water has been taken into the bypass from the Sacramento River via Butte Slough. Water from the east borrow pit flows into Nelson Slough which crosses the bypass to the west borrow pit. The west borrow pit water then flows into the Sacramento Slough, which has its confluence with the Sacramento River at mile 80.5.

Under flooded conditions, Sutter Bypass water enters the Sacramento River between mile 80 and mile 84. Most of the floodflow continues across the river, over the Fremont Weir, and into the Yolo Bypass. The floodwaters continue to flow south to just above Rio Vista (mile 13) where they enter the Sacramento River Delta.

Most tributary flows in the lower-middle reach have been diverted through the CBD to the west and the Butte and Sutter Basins to the east. Other than the agricultural drains (CBD at mile 90 and Sutter Bypass via Sacramento Slough at mile 80.5), the only other major tributary inflow in this reach is the Feather River just below mile 80 near Verona.

### General Water Quality (Lower-Middle Reach)

Water quality in this reach is influenced by agricultural drainage and the Feather River. Water quality problems associated with the CBD have been studied extensively, while virtually no water quality information was found for the Sutter Bypass. Many of the problems related to the CBD are due to erosion and leaching from the highly alkaline soils (CDWR 1964). Significant quantities of suspended sediments, turbidity, dissolved solids, electrical conductivity, and nutrients, as well as pesticides in some cases, are added to the Sacramento River via the CBD. It was estimated that 269,000 tons of soil are eroded yearly in the Colusa Basin (U.C. Davis 1980a). Suspended sediments are highest during the non-irrigation season and are associated with peak storm events (U.C. Davis 1980a, 1980b. And 1981).

Historical CDWR data from the early 1960s classified the CBD waters as sodium-magnesium bicarbonate in nature. However, in 1980 U.C. Davis identified the

dominant soluble ions as sodium, sulfate, and bicarbonate. Highest mineral content is found during the irrigation season when the CBD water is used and reused for agricultural purposes.

High concentrations of DDT and its breakdown products were found in CBD catfish and clams during the mid-1960s. However, low DDT residues were found in the water, suspended solids and bottom sediments (Hunt 1964, 1965, 1966, and 1967). This illustrates the value of using biological tissue samples for indicating pesticide contamination in an aquatic system. Although the use of DDT has been banned in this country, problems in the CBD associated with the persistence of DDT or its breakdown products are not known. Other pesticides have been detected from time to time, but usually not at problem levels. The herbicide molinate (Ordram), which is extensively used in rice culture, was found during the spring and early summer in 1980 and 1981 (U.C. Davis 1980b, 1981). Ordram concentrations in the CBD were found to steadily increase from April to June in 1981. Concentrations then rapidly decreased in June after its use period and were below detection limits during the rest of the year.

The Feather River provides a substantial quantity of high quality water to the Sacramento River. The Feather River has its origin in the volcanic formations of the Sierra Nevadas. It flows southwest to a point near Oroville, where it has been impounded behind the California State Water Project's Oroville Dam. Oroville Reservoir has a storage capacity of approximately  $3.5 \times 10^6$  acre-feet. The dam was completed in 1968 and provides hypolimnion release waters to the Feather River. From Oroville, the Feather flows south through the Sacramento Valley where it is joined by two major tributaries. The Yuba River joins the Feather River at Marysville, while the Bear River has its confluence about 15 miles farther downstream. The Feather River then has its junction with the Sacramento River at river mile 80. The Feather River waters are generally lower in turbidity, suspended solids, dissolved solids, electrical conductivity, and nutrients than the Sacramento River (historical data).

Water temperatures in this reach of the Sacramento River continue to increase in a downstream progression, except during the winter months when temperatures either decline slightly or hold fairly constant as the river flows downstream (CDWR 1962, and current data). During most of the year, water temperatures increase below the Colusa Basin Drain outfall (Hayes et al. 1978) and then decline below the Feather River confluence (USGS 1978b). However, USGS (1978b) found the Feather River to be warmer in August than the Sacramento River, resulting in continued warming below their confluence.

Seasonal and diurnal temperature fluctuations are greater in this reach than at the upper two reaches (historical data). Current data collected by CDWR show temperatures in this reach to vary from a low of 48°F in January 1984 to a high of 71°F

in August 1983.

Turbidity, suspended solids, and color are also greater in this reach than at the upper reaches, which is largely due to irrigation return flows, erosion, and algal production (CDWR 1962). However, the pattern is less evident during the late summer and early fall when flows and turbidities are lowest. Highest turbidity values occur during periods of high rainfall and increased flows (CDWR 1970, 1972; U.C. Davis 1979). The CBD contains significant concentrations of suspended solids that raise the turbidity of the river, especially during storm runoff. The river water contains one-fifth the suspended solid concentration, while having two times the organic content as the CBD (U.C. Davis 1980a). Suspended solids and turbidity values are highest immediately below the CBD outfall, but decline to slightly above the values found above the outfall as the river moves downstream (Hayes et al. 1978, U.C. Davis 1981). Color also increases below the CBD outfall, with the highest values occurring in late September with increased releases from rice fields and the resultant increase of organic matter in the drainage waters (U.C. Davis 1981).

The increase in turbidity as the river flows downstream is interrupted at the confluence with the Feather River. The inflowing low turbidity waters of the Feather River result in decreased turbidity in the Sacramento River below their junction. Current CDWR data showed turbidity values in this reach to range from a low of 2.5 FTUs in October to a high of 46 FTUs during a storm in late November.

The pH remains relatively constant in this reach with values ranging from 7.1 to 7.5. Values are somewhat more alkaline in the CBD, but are slightly lower in the Feather River (USGS 1978b).

Electrical conductivity in the lower-middle reach follows a pattern similar to the upper two reaches. Once again, historical data indicate that ECs are generally higher in the winter and lower in summer. However, hydrologic conditions interrupt this pattern from time to time. Electrical conductivities in 1970 were lowest during a January flood (CDWR 1970). At other times ECs have been lowest in the spring due to heavy runoff from snowmelt (CDWR 1962). In addition, agricultural practices in this reach may interrupt the seasonal pattern. Current data collected by DWR showed a substantial increase in EC in this reach during mid-September 1983. This increase resulted in the highest EC values observed during the year. Since rice fields are generally drained for harvest near this period of time, it seems likely that the increased ECs were a result of agricultural drainage. Conductivities during 1983 and 1984 ranged between 115 and 175  $\mu\text{mhos/cm}$ . However, no stations were located below major agricultural drains where higher ECs may have occurred.

Conductivities in the lower-middle reach of the river are greater than those at the upper two reaches (CDWR 1970, 1973; current and historical data). Substantial increases have been noted below the CBD outfall (mile 90)(Hayes et al. 1978, U.C.

Davis 1981). However, Hayes et al. (1978) found the higher ECs below the CBD to decline downstream and stabilize slightly above values found in the river above the outfall. This was probably a result of more complete mixing of the CBD plume and the settling of suspended solids as the river moves downstream. DWR (1962) indicated that irrigation return waters increase EC in the river during most of the year except during the spring. No information was found on the impacts of agricultural drainage on the river from Reclamation District 108 (near mile 99.5) and the Sutter Bypass (mile 80.5).

The trend of increased EC as the river moves downstream is interrupted at the confluence with the Feather River (mile 80). The Feather River has had lower EC water both before and after construction of Oroville Dam. Therefore, the resultant mixture of Feather River and Sacramento River waters predictably has an EC greater than the former but less than the latter river above their confluence (CDWR 1962, 1970, 1973; USGS 1978b).

Nutrient concentrations in this reach tend to increase in a downstream progression, but decrease below the confluence of the Feather River (CDWR 1970, 1973; USGS 1978b). Phosphorus and carbon concentrations are higher in the Sacramento River than the Feather River (USGS 1978b). Nutrient concentrations are nearly always higher in the agricultural drains than the main stem and result in increased concentrations in the river below their outfalls.

Current and historical data show greater seasonal fluctuations of dissolved oxygen (DO) in this reach than at the upper reaches. This is largely due to seasonal temperature regimes. Concentrations are highest in the winter when temperatures are lowest and lowest in the summer when temperatures are highest. Dissolved oxygen concentration decreases slightly downstream, due to increased temperatures and increased waste discharges (CDWR 1962). The Feather River, for the most part, has higher concentrations of oxygen than the Sacramento River (USGS 1978b). However, under low-flow conditions when the Feather River sometimes becomes warmer than the Sacramento, the opposite trend is seen (higher DO in the Sacramento versus the Feather Rivers). The diurnal DO cycle in this section of the river follows a predictable pattern. During August, oxygen concentrations increase in the afternoon due to photosynthetic activity and then decline at night (USGS 1978b). Similar trends are seen in the Feather River during the same period. During November, however, no clear diurnal DO cycles were observed in the Feather River and Sacramento River below the Feather River. Dissolved oxygen levels never declined significantly, indicating no waste assimilation problems in this reach. However, no recent diurnal cycling data was found for the Sacramento River below any major agricultural drains.

### Biological Water Quality (Lower-Middle Reach)

No current bacteriological data were found for this reach of the Sacramento River. The California Department of Water Resources (1962) found increases in coliform bacteria below agricultural drains during 1960 and 1961. The most substantial increases were found below the Reclamation District 108 outfall (mile 98.5) and the Sutter Bypass outfall via Sacramento Slough (mile 80.5). It is noteworthy that while increased total coliform concentrations were found, fecal coliform concentrations did not increase below these agricultural drains.

Phytoplankton concentrations and diversity continue to increase in this reach from that at the upper two reaches (CDWR 1962; USGS 1974; Britton 1977). Highest concentrations were observed at a site above Knights Landing. Diatoms have usually dominated the planktonic community both in concentration and species richness (CDWR 1962; USGS 1974; Britton 1977). The California Department of Water Resources in 1960 and 1961 found that blue-greens and other phyla of phytoplankton were present only in low concentrations. In addition, zooplankton seldom comprised over one percent of the total planktonic community. The U. S. Geological Survey (1978b) in 1972 and 1973 found three major phyla including diatoms, green algae, and blue-green algae, but diatoms still dominated. In comparison of the CDWR and USGS data, Britton (1977) found phytoplankton concentrations to be higher in 1960-61 than in 1972-73. In addition, diatom concentrations were significantly higher statistically in 1960-61, while blue-green concentrations were higher in 1972-73 but not statistically. Lowest phytoplankton concentrations occur during the winter. Increases in plankton populations strongly correlated to increased water temperatures in the river (CDWR 1962). No further Sacramento River plankton studies were found that were conducted after 1972-73.

The periphyton community in this reach continues to be dominated by diatoms with respect to density and biomass. Species richness and frequency of occurrence of periphyton have increased from that at the upper two reaches. However, productivity (biomass) decreases in this reach, which is due largely to increases in water depth, turbidity, and sediment production (Britton 1977).

The impact of the CBD discharge on Sacramento River attached diatoms was investigated by Hayes et al. (1978). Diatom density, chlorophyll a, b, and c, and organic matter were significantly lower in the CBD than the river above the CBD outfall. These biotic parameters were also found to be significantly lower in the river below the CBD outfall than above. With further movement downstream, however, the parameters steadily increased to levels similar to those found at the station above the outfall.

Benthic macroinvertebrates were studied in this reach during 1960-61 (CDWR 1962) and 1972-73 (USGS 1974; Britton 1977). Samples in both cases were collected with a dredge. In both studies, this reach was found to be the least productive with

respect to density, diversity, and biomass of organisms. Community structure was similar between the two studies, with midge larvae, oligochaete worms, and corbiculid clams being the dominant organisms. Similar to the upper two reaches, the density of benthic organisms increased from May to September and then decreased through April. No further studies conducted after the early 1970s on benthic macroinvertebrates were found. Faunal drift studies, however, were conducted by USGS (1978b) on the Feather River and the Sacramento River, both above and below the confluence of the Feather River. Drift organisms were composed of both terrestrial and aquatic insects and were mostly aphids, blackfly larvae, and midge larvae. Peak drift periods occurred during evenings and early mornings.

## Overview of Findings

The Sacramento River with its main stem reservoirs, tributary impoundments, and flood control projects is a highly regulated system. The stretch of river covered in this review flows in a well-defined channel above Red Bluff, meanders somewhat freely from Red Bluff to Colusa, and is virtually canalized by flood control and reclamation levees below Colusa. The river has several beneficial uses, including municipal, industrial, and agricultural water supply, power generation, salinity control in the Delta, navigation to Sacramento, fish propagation, flood control, disposal of wastes, and recreation.

Conflicting land use practices along the river are a major issue, particularly from Chico Landing to Red Bluff. Replacement of the riparian zone with high economic value developments (i.e. orchards and housing) has resulted in a controversial bank protection project.

Much of the water quality information found for this review is old or outdated. An intensive water quality and biology evaluation of the Sacramento River has not been performed in the last ten years.

Waters of the Sacramento River are generally of good to excellent quality for most beneficial uses. However, there appears to have been some cultural eutrophication in the upper river system, as indicated by an increased abundance of benthic macroinvertebrates over the past 20 years. In addition, blue-green algae (which are indicators of eutrophication) were found to dominate the phytoplankton community in September 1973 at Bend Bridge (mile 258). However, current information on phytoplankton was not available.

Computer predictions for electrical conductivity in the Sacramento River during 1990 indicate that the average conductivity will increase over historical values. Even with this increase, it is predicted that the Sacramento River will have good quality water and that extreme values will have been reduced due to increased regulation by

dams and reservoirs.

The highly regulated nature of the Sacramento River system has resulted in a depression of several physical and chemical regimes, both seasonally and diurnally. By maintaining a higher base flow, water quality has probably been improved in the river when compared to pre-Shasta Reservoir conditions. Higher base flows have also increased the waste assimilative capacity of the river. In addition, the development of better municipal waste treatment facilities has also improved water quality conditions in the river.

Continued municipal, industrial, and agricultural growth in the northern central valley may have the potential for creating future water quality problems. Agricultural drainage in the lower-middle reach is already a substantial non-point source of pollution, particularly with respect to nutrient loading, suspended sediments, dissolved constituents, and, in some cases, pesticides.

Acid mine drainage near Keswick Reservoir has been and continues to be a major source of heavy metal pollution to the Sacramento River. Currently, substantial time, energy, and money is being spent to develop and evaluate measures for alleviation of the problem.

### Future Study Needs

Due to a lack of time and funding, several reports and studies could not be reviewed. Most of the information in this report was from materials on file in the Northern District of the California Department of Water Resources. In addition, pertinent information was reviewed from three computer literature searches (Water Resources Abstracts, National Technical Information Service, and Aquatic Science Abstracts). It would be valuable to review the reports and studies not included in this review, as well as to update this review every few years to include newer studies.

There is a need to find more information on bacteriological quality of the Sacramento River. The only information found (CDWR 1962) is now outdated. Possible information sources include the California Department of Health Services, county health departments, and the Central Valley Regional Water Quality Control Board.

Water quality and biological data collected during the drought years of 1976 and 1977 present an excellent opportunity to evaluate low-flow conditions in the Sacramento River. It would be valuable to compile and analyze such data to determine potential water quality problems in the river and to evaluate the ability of the river to assimilate agricultural, municipal, and industrial wastes under worst case (low-flow) conditions.

The California Department of Water Resources in the early 1960s conducted an intensive water quality and biological study on the Sacramento River. Some of the components of the study included basic physical and chemical water quality, intensive diurnal studies, bacteriological quality, plankton and periphyton analyses, and analysis of benthic macroinvertebrate communities. The study was set up to provide baseline information on conditions in the Sacramento River. It was recommended that intensive surveys be conducted periodically to determine long-term trends in water quality. Since the Sacramento River is of vast importance to the State Water Project as well as other important beneficial uses, it seems reasonable to conduct periodic intensive water quality surveys. However, it was not until the early 1970s that a toned-down version of the 1960s study was conducted by the U. S. Geological Survey, and similar work has not been completed in the last 10 to 12 years. Intensive water quality and biological studies on the Sacramento River should be conducted on at least a five-year rotation. Stations should bracket major municipal, industrial, agricultural, and tributary inflows to determine their impacts on the river. In addition, yearly analyses should be conducted on a few key stations to identify any trends or anomalies occurring between the intensive study years.

A reevaluation of municipal, industrial, and agricultural growth and its potential impact on the quality of future Sacramento River water supplies would be valuable. The California Department of Water Resources' 1971 electrical conductivity model could be analyzed to see how well its 1990 predictions are meeting trends indicated by current information.

Safe dilution factors for mixing of the heavy metal laden Spring Creek waters in Keswick Reservoir have been determined for salmon and steelhead. These dilution factors were determined for complete and instantaneous mixing. Since some fish kills can still happen when dilution schedules are met, it seems likely that complete, instantaneous mixing does not occur. A valuable study might include determination of travel times of Spring Creek effluent into Keswick Reservoir and the distance below the confluence of Spring Creek that complete mixing actually occurs under different flow conditions. In this way better dilution factors could be determined. The study could be accomplished with the use of electrical conductivity as a natural marker or by the use of fluorescence dyes.

Monitoring of toxic substances (heavy metals and synthetic organic compounds) in fish and invertebrates of California rivers, streams, and lakes has been conducted by the California Department of Fish and Game and California State Water Resources Control Board since 1976. These have been valuable studies in determining problem areas in the State. Only a single Sacramento River station, located below the City of Sacramento, is sampled. Similar studies would be valuable on the river above and below major agricultural drains and in the Spring Creek area near Keswick Reservoir, especially in light of the increasing agricultural, municipal, and industrial activities and

their associated waste discharges.

Since bank protection is both controversial and expensive, further studies on its impacts and value are warranted. There is a need to better assess morphological changes in the river (i.e. downcutting, channelization, and scouring) that might be caused by bank protection (riprap). In addition, the impacts on the Sacramento River anadromous fisheries and fish habitat should be further addressed. The California Department of Fish and Game has recommended inventorying the quantity and quality of spawning habitat from Red Bluff to Chico Landing. In addition to the suitability of riffle gravels and gravel recruitment for spawning, an evaluation of food production (benthic invertebrates) capabilities of the riffle habitats would be valuable.

One argument for bank protection is to reduce sediment loading in the Sacramento River via bank erosion. There is a need for the development of a detailed sediment budget of sources and sinks for sediment production in the Sacramento River drainage. While the Corps of Engineers has developed such a budget, they have failed to incorporate over-bank deposition during flood periods, which may be a very substantial factor. Further study may indicate other sources deserving attention (i.e. basin and watershed management).

The impact of agricultural drainage from the Colusa Basin Drain on Sacramento River water quality has received much attention. However, virtually no water quality information on agricultural drainage from the Sutter Bypass via Sacramento Slough was found during this review. Since the volume of outflow from Sacramento Slough is similar to the Colusa Basin Drain, a study on the quality of Sacramento Slough water and impact on the Sacramento River may be warranted.

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## Appendix A

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## Appendix B

### Annotated Bibliography of Sacramento River Reports, Publications, Memorandums, and Letters

1. Academy of Natural Sciences of Philadelphia 1956. Sacramento River, Keswick Reservoir and vicinity, stream survey report for the State of California.

Through diatometer analysis it was found that the Sacramento River between the confluence of Spring Creek and one-half mile below Keswick Dam was severely affected by heavy metal pollution. There was no evidence of pollution from Shasta Dam to one-half mile above Spring Creek and from Lake Redding to the bridge on old Highway 44. Boulder and Slickrock Creeks, tributaries to Spring Creek, were the main sources of the pollution. The waters were very acid and contained high concentrations of iron, zinc, copper and probably other heavy metals. Part of the

metals were precipitated in Keswick Reservoir as orange-gray muds (rich in iron) and also gray-green pyrite muds.

Through fish toxicity tests it was found that the orange muds were apparently stable in the reservoir while the gray-green muds were much more toxic. However, both muds had high heavy metal content. When Spring Creek water was diluted 1:12, all test fish (king salmon) died within four hours. This condition existed for over 12 hours in the reservoir during a November 1955 freshet. A mixture of boulder and Slickrock Creek water at a dilution of 1:55 was toxic to king salmon fingerlings.

2. Advanced Environmental Consultants, Inc. 1983. Control of acid and heavy metal discharge from Balaklala, Keystone, and Shasta King Mine sites, West Shasta Mining District, Shasta County, California. Prepared for Water Quality Control Board, Project No. 83-101.

This study began in December 1982. The geology, hydrology and physicochemical conditions were investigated to determine the feasibility of eliminating or reducing toxic discharges from Balaklala, Keystone, and Shasta King Mines. An evaluation of the use of Na-EDTA for detoxification and stabilization of metals in the mine spoils is included as an appendix.

A brief history of mining and problems is presented. In September 1978 the Water Quality Control Board adopted discharge requirements for the mine owners (Silver King Mines, Inc.). In June 1980 a project was built to divert water around a stope "Glory Hole" of the Balaklala Mine. When operational, the diversion effectively reduced the outflow of water from the mine. The actual metal load, however, was not reduced, since metal concentrations of the effluent increased. In November 1980 a concrete air seal was placed in the Weil Portal of the Balaklala Mine. When no improvement was observed in the effluent, a total hydraulic seal was made in March 1982. The resultant copper and zinc concentrations in West Squaw Creek were reduced 90 percent.

A 1982-83 DWR study showed the Balaklala portal to be the most significant source of pollutants. During low flows, a substantial load of metals entered storage in mine dumps, subsurface fracture systems and streambeds. These metals were later released with increased runoff.

The goals identified for the West Squaw Creek drainage were the elimination of fish kills and restoration of diverse aquatic life in the stream.

The findings and recommended control measures include:

- the Weil Portal seal has effectively eliminated a major percentage of acid mine drainage in the area,
- the Balaklala Portal currently contributes the greatest percentage of pollutants,

- both the upper and lower Balaklala portals can be sealed by concrete plugs,
  - bulkhead seals are recommended for the keystone portal and possibly the East Keystone Portal along with further investigation,
  - surface flow should be diverted away from the Glory Hole of the Balaklala Mine,
  - a detailed engineering analysis is recommended on blasting techniques to collapse and plug the 'Glory Hole',
  - pollution loads from the Shasta King Mine were inconclusive and no recommendations were made,
  - grading, crowning, terracing and berming of mine dumps were not found feasible,
  - promising results were found by treating mine spoils with lime and Na-EDTA, but further research is needed.
3. Anonymous. No date. Information sheet for Mammoth Mine, Shasta County (Sharon Steel Corporation).

The mine is located 13 miles Northwest of Bedding. Section 32, T34N, R5W, and Section 5, T32N, R5W, near Shasta Dam. The primary source of acid mine drainage is the main adit of the Mammoth Mine that discharges onto and through an ore-containing pile and into Little Backbone Creek. The discharge contains an annual average of 27 mg/L copper, 47 mg/L zinc and 0.25 mg/L cadmium, with a pH of 2.6. Average annual loading of Cu and Zn from the main adit is 188 lbs/day.

The California Regional Water Quality Control Board, Central Valley Region, adopted waste discharge requirements in September 1978 for Mammoth Mine. The requirements included a preliminary engineering report on the feasibility of reducing or eliminating acid mine wastes. The report was not completed.

On March 27, 1981, the Regional Board adopted new waste discharge requirements (Order No. 81-047). In 1979 a letter was received from Sharon Steel Company discussing some preliminary concepts: diversion of mine effluent away from waste tailings; construction of a copper precipitation facility (not economical); and sealing surface portals, which would be unduly expensive and preclude future use of the tunnels.

4. Benoit, R. J.; J. Cairns, Jr.; and C. W. Reimer 1967. A limnological reconnaissance of an impoundment receiving heavy metals, with emphasis on diatoms and fish, pp. 69-99. In: American Fisheries Society, Southern Division Reservoir Committee, Reservoir Fishery Resources Symposium, April 5-7.

The purpose of this study was to determine the cause of the fish kills which were occurring sporadically in the upper Sacramento River below Keswick Reservoir. The study, made in 1955 and 1956, was divided into four phases: (1) general reconnaissance and biological survey, (2) diatometer survey, (3) chemical survey, and

(4) toxicity bioassays of certain waters and sediments using fingerling salmon. The study area was from the Sacramento River south of Redding upstream to Lake Shasta. Twenty-one sampling stations were used.

The biological survey indicated that the upper tributaries of Keswick Lake had a healthy variety of flora and fauna, but Spring Creek (and its tributaries) were severely degraded by acid mine drainage. Flat Creek also showed an "unhealthy biota. The degrading influence of Spring Creek (as indicated by diatometers) was detected at the lower Keswick Lake stations and during one period of heavy runoff in the upper portion of Lake Redding.

The chemical survey showed Spring Creek water to have a very low pH and to contain high concentrations of iron, copper, and zinc. The Spring Creek delta "muds" also contained large quantities of metals and hydrous iron oxides were sedimented in Keswick Lake below the confluence of Spring Creek.

The bioassay studies showed Spring Creek water and sediments to be very toxic to salmon fingerlings. Analysis of various flow conditions indicated that at certain times toxic conditions could develop in lower Keswick Lake and upper Lake Redding because of acid water and heavy metals discharged from Spring Creek.

5. Brennan, R. 1963. Reconnaissance study of the chemical quality of surface waters in the Sacramento River Basin, California. Geological Survey Water Supply Paper 1619-Q. U. S. Government Printing Office, Washington, D. C.

Water use, geographical, climatic and geological characteristics of the Sacramento River Basin are discussed. The chemical quality is directly related to the geology of the area. Streams draining the crystalline rocks north and east of the valley are low in dissolved solids and conductivity. Streams from the coastal sedimentary rocks have higher dissolved solids and conductivity. From Redding to Suisun Bay the Sacramento River flows through recent sediments. The major tributaries originate in the Sierra Nevadas.

Data were collected from 26 periodic and 3 daily collection stations from 1951 through 1958. Calcium, magnesium, sodium, potassium, bicarbonate, chloride, boron, hardness, conductivity, and percent sodium were determined for the periodic samples. In addition, silica, sulfate, nitrates, fluoride, and dissolved solids were determined from May and September periodic samples and on all composite samples from daily collection stations.

Waters of the Sacramento River Basin are of the calcium and magnesium bicarbonate type. Three agricultural drains between Knights Landing and Sacramento return waters with concentrated dissolved solids. The river at Sacramento, however, shows little increase in dissolved solids content because of the effect of dilution by two major tributaries (American and Feather Rivers).

6. Britton, L. J. 1977. Periphyton and phytoplankton in the Sacramento River, California, May 1972 to April 1973. J. Res. U. S. Geol. Surv. 5(5): 547-559.

Periphyton and phytoplankton samples were collected monthly at five sites in the Sacramento River between May 1972 and April 1973. The sampling sites covered an area from Bend Bridge near Red Bluff to Knights Landing.

Periphyton were analyzed for species identification and biomass, while phytoplankton were analyzed for species identification and concentration. The results were used to assess biological water quality conditions in the river and to compare phytoplankton at three sites with those collected in 1960-61.

Diatoms were the dominant group in both numbers and types of periphyton and phytoplankton. The number of genera and frequency of occurrence of periphyton increased downstream. However, the periphyton biomass decreased downstream and with succeeding monthly sampling periods. The highest productivity was at a site below Red Bluff, probably because the Red Bluff Diversion Dam provides optimum conditions for periphyton growth. The decreasing productivity downstream was probably a function of higher sediment concentrations.

Phytoplankton concentrations and diversity increased downstream. The highest concentration was found at a site above Knights Landing in September. Fewer phytoplankton genera were collected in 1972-73 than in 1960-61, but the generic composition was similar. Total phytoplankton concentrations were nearly always higher in 1960-61 than in 1972-73. Green algal concentrations were significantly higher ( $p < 0.05$ ) at Colusa and diatoms were significantly higher at all three sites in 1960-61. Blue-green concentrations were higher 1972-73, but differences were not statistically significant.

7. California Department of Fish and Game. No date. Toxicities of copper, zinc, and cadmium mixtures to juvenile chinook salmon. Undated prepublication copy by B. J. Finlayson and K. M. Verrue, Water Pollution Control Laboratory, Rancho Cordova.

Continual flow toxicity tests were conducted during 1979 and 1980 to determine the acute toxicological interactions of copper, zinc, and cadmium to juvenile chinook salmon (*Oncorhynchus tshawytscha*). Control fish without metals had a mean survival of 99.6 percent. As the dissolved metals were increased, the mortality of the salmon increased. The fish were most sensitive to cadmium, moderately sensitive to copper and least sensitive to zinc.

Mixtures of two and three metals had variable topological effects. Contrary to other studies, copper-zinc mixtures showed no toxicity interaction between the two metals at

higher copper-zinc ratios. Copper-cadmium mixtures were partially additive. There was no toxicological interaction with the zinc-cadmium mixture.

8. California Department of Fish and Game. No date. Zinc, aluminum and iron toxicity from Spring Creek Debris Dam, Sacramento River Basin, Shasta County, California. A preliminary proposal by Brian J. Finlayson, Water Quality Biologist, Calif.

Runoff from Spring Creek drainage has caused numerous fish kills in the Sacramento River. In 1963 minimum releases from Spring Creek Debris Dam were calculated for "safe" heavy metal concentrations in the Sacramento River. However, only copper toxicity was considered, no margin of safety was provided, they were based on immediate and complete dilution, and the toxicity tests were of short duration (96 hr). Consequently, occasional fish kills still occur when releases from Spring Creek Dam approach maximum allowable flows.

The purpose of this study would be to determine "safe" release schedules based on Spring Creek zinc, aluminum and iron concentrations. A treatment process to remove copper from Spring Creek Debris Dam releases is planned.

She proposed study was to establish  $LC_{50}$  and ILL (incipient lethal level) for Zn, Al and Fe in both 48-hr and 96-hr studies at various pHs ranging from 5.0-7.5. Next,  $LC_{50}$  and ILL were to be determined for a mean ratio of Zn:Al:Fe in a 96-hr continuous flow study at various pHs. Then the effects of increases or decreases of various constituents was to be tested. Finally, a 30-day continuous flow at various pHs for mean Zn:Al:Fe was to be done to establish  $LC_{50}$ , ILL, and sublethal effects on behavior and growth.

In addition, a review of some heavy metal toxicity works is presented.

9. California Department of Fish and Game 1953. Water pollution investigations; a preliminary report on the upper Sacramento River copper pollution, Shasta County.

This report includes locations, classifications and maps of sources of copper pollution in and around the Shasta and Keswick Reservoir area. In addition, water samples from 30 stations on tributaries (Spring Creek, Motion Creek, West Squaw Creek, Shoemaker Gulch and Backbone Creek) below several mines were collected in June 1952. The samples were analyzed for pH, specific conductance, acidity, alkalinity, copper and zinc. Finally, an evaluation is presented of the mine tunnel and shaft sealing program that was conducted on Little Backbone Creek in 1943.

Historically, heavy loads of dissolved copper entered Shasta and Keswick Reservoirs

from abandoned mines and tailings. Copper ores were oxidized into water soluble salts that were washed into the streams with the first rains. Resultant fish kills were reported in 1940, 1944 and 1949. In 1944, an estimated one-third of the fall salmon run died before spawning. It is suggested that resident fish populations may have built up a tolerance to higher copper concentrations.

The mine sealing program was considered ineffective. All the seals were broken; however, it was not known if the mines were properly sealed originally.

10. California Department of Fish and Game 1974. Investigation of mine drainage related fish kills in the Little Squaw Creek Arm of Shasta Lake, Shasta County, California. Environmental Services Branch, Admin. Report No. 74-2.

The objective of this paper was to document fish losses relative to mine drainage pollution, taking into account the magnitude of the fish kills, species composition, timing of the fish kills, and the delineated toxic area in the Little Squaw Creek Arm of Lake Shasta.

The Little Squaw Creek Arm was sampled weekly during 1968-69 unless a fish kill was in progress, in which case more extensive sampling was undertaken. Vertical profiles were taken at various locations to determine copper concentrations in the water column.

Copper concentrations at toxic levels were found from the mouth of Little Squaw Creek to a distance of 1,645 meters off shore. Copper and pH levels in the stream were in the toxic range throughout the study (pH <5.0, copper >0.025 mg/L). However, vertical profiles of the lake showed the pH to be within the acceptable limits for fish survival. Bottom copper samples were consistently higher than surface samples.

Copper concentrations decreased during the rainy season of January through April, but increased in late spring due to lower flows (less dilution). Fish kills occurred under both conditions. Kills were not observed from September to December, but toxic conditions did exist during that period. The observed kills occurred from January until August.

Salmonid kills were related to the time of year, area where the fish were planted, and the physical and chemical relationships of heavy metals and dilution water.

11. California Department of Fish and Game 1975. Mine drainage from Balaklala, Keystone, Shasta King and other mines into Little Squaw Creek Arm of Shasta Lake, Shasta County, California. Region 1 Memorandum.

Data were collected at the Little Squaw Creek Bridge from March 18, 1975 through August 1, 1975. The parameters looked at included water temperature, pH, electrical

conductivity, turbidity, and copper. Water temperature (4.5-18.0 C), electrical conductivity (93-480  $\mu\text{mhos/cm}$ ) and copper concentration (0.61-3.5 mg/L) increased as flows decreased. Turbidity (4.5-19.0 JTU) and pH (3.2-4.2) decreased with decreased flows.

12. California Department of Fish and Game 1975. Mine drainage from Bully Hill and Rising Star Copper Mines, Squaw Creek Arm, Shasta Lake. Region 1 Memorandum.

Data were collected on March 14, 1975, from four stations on Town Creek and three stations on Horse Creek, which are tributaries to Shasta Lake.

Town Creek pH ranged from 5.7-6.5, conductivity (EC) from 149-255  $\mu\text{mhos/cm}$ , copper from 2.05-2.73 mg/L and zinc from 4.25-5.5 mg/L. Ten feet from the confluence of Town Creek in Shasta Lake the pH was 6.6, EC was 110  $\mu\text{mhos/cm}$ , copper was 0.32 mg/L, and zinc was 0.24 mg/L.

The pH of Horse Creek was higher (6.6-6.8), while the EC (65-88  $\mu\text{mhos/cm}$ ), copper (0.13-0.29 mg/L) and zinc (0.09-0.2 mg/L) values were substantially lower.

13. California Department of Fish and Game 1975. Mine drainage from Bully Hill Copper Mine, Squaw Creek Arm of Shasta Lake. Region 1 Memorandum.

Water samples for two stations on Town Creek were collected on June 24, 1975. Analyses of the samples found a pH of 4.3, turbidities of 1.5-1.7 JTU, EC's of 385-445  $\mu\text{mhos/cm}$ , copper values of 4.34-4.53 mg/L, and zinc values of 7.0-8.5 mg/L. Eight meters from the mouth of Town Creek in Shasta Lake the pH was 7.3, turbidity was 2.7, EC was 115  $\mu\text{mhos/cm}$ , copper concentration was 0.34 mg/L, and zinc was 0.18 mg/L.

14. California Department of Fish and Game 1977. Proposed toxicity testing program for the Spring Creek acid mine waste during fiscal years 1977-1978, 1978-1979, and 1979-1980. Water Pollution Control Laboratory.

This paper outlines a proposal for research to determine safe levels of zinc and copper from acid mine wastes in the Spring Creek drainage on anadromous salmonid populations in the upper Sacramento River. "Safe" implies a level of zinc and copper which will not adversely affect populations of anadromous salmonids. Toxicological examinations of wastes on eggs, alevins, fry and juveniles of chinook salmon and steelhead trout were proposed for short-term (96-hr) and long-term (60-day) exposures.

15. California Department of Fish and Game 1977. Progress report: 1977 temperature predictions for the Trinity and Sacramento Rivers. Region 1.

This report makes temperature predictions for Trinity, Wiskeytown and Shasta Reservoir release waters. The predictions were intended to evaluate temperature conditions both with and without temperature control curtains.

The mean temperature of water released into the Trinity River should be suitable for normal spawning beginning in early September. Without a curtain in Shasta Reservoir, successful spawning was not expected in the Sacramento River until late October when the mean temperature at Balls Ferry would be 59-60°F. With the curtain, this temperature could be decreased to 56°F.

16. California Department of Fish and Game 1982. Sacramento River and tributaries bank protection and erosion control investigation - evaluation of impacts on fisheries. Bay-Delta Fishery Project.

This report describes the results of a one-year study on the effects of riprap on chinook salmon. A historical overview of river use is presented. Methods involved the use of drift net sampling for invertebrates, diet analysis of young salmon, electrofishing and aerial surveys on paired sites of riprap and cut-bank areas.

The insect families, Chironomidae (midges), Baetidae (mayflies) and Aphidae (aphids) comprised 72 percent of the salmon diet in both areas. These three families composed 53-54 percent of the insect drift. No statistical difference was found between riprap and cut-bank areas with respect to the quantity of drift organisms.

Only one-third the number of salmon occurred in the riprap versus the cut-bank areas. This was statistically significant at the 95 percent confidence level.

Higher species diversity (Shannon-Weaver) for fish communities was found in riprap areas. Most of the other species compete with salmon for food and some prey on salmon fry.

Riprap will decrease spawning gravel recruitment by reducing lateral movement of the river, which exposes large quantities of gravels from subsoil layers.

A reduction in salmon fry survival was predicted from bank stabilization. Estimated economic loss to sport and commercial fishing is presented.

Recommendations include governmental procurement of a meander belt from Chico Landing to Red Bluff, the use of flatter slopes and smaller substrate when riprapping to enhance insect development and decrease turbulence, and planning alternatives for spawning and rearing facilities that will support impacted salmon runs.

Additional studies were recommended for the river between Red Bluff and Chico

Landing, including: an inventory of spawning areas, developing a sediment budget, estimating gravel recruitment through lateral migration of the river, assessment of morphological changes in the river as a result of riprapping, determine if fish-habitat relationships are similar in downstream areas, and conducting an annual photographic inventory of spawning areas in all reaches of the Sacramento River.

17. California Department of Water Resources 1960. Upper Sacramento River development. Water Quality Investigation.

Studies were conducted on ground and surface waters of the Sacramento River watershed between Keswick Dam and Red Bluff. Major tributaries include Clear, Cottonwood, Cow, Bear, Battle and Paynes Creeks. Objectives were to determine existing quality conditions of surface and ground water, to detect quality problems, and to evaluate quality aspects of proposed water resources projects.

Water quality limits for water export to water deficient areas were developed by a board of consultants and are presented in this report.

Surface waters of the upper Sacramento River were found to be of excellent mineral quality and suitable for most beneficial uses. The water was classified as calcium-magnesium bicarbonate in type in most cases. The upper reaches of Churn and Stillwater Creeks, however, were typed as magnesium-sodium bicarbonate and Clear Creek was calcium-sodium bicarbonate in type.

Surface water in the area was rated good to excellent for agriculture and satisfactory in mineral quality for domestic and municipal use.

Future water quality problems could develop from irrigation return flows and development of the timber by-product industry.

Streams draining the Iron Mountain region were acidic, high in conductivity and contained undesirable concentrations of copper, zinc, iron, aluminum and other toxic salts.

18. California Department of Water Resources 1960. Water quality objectives for the State Water Project.

This report presents information on water quality objectives to be met for water transported to Southern California. The Sacramento River is the principal conveyance channel for the project.

Routine and emergency operations, maintenance and special studies are discussed. A summary of the Sacramento River Monitoring Program (Bulletin No. 111) is presented. Recommendations are made including determination of river travel times,

determination of organic materials and pesticides in the Colusa Basin Drain, establishing temperature effects of agricultural drain waters on the river, and monitoring of tributary water quality.

19. California Department of Water Resources 1961. Progress report on upper Sacramento River basin investigation.

The study area included the entire drainage basin of the Sacramento River from Shasta Dam to Red Bluff. Runoff averaged two million acre-feet annually. The purpose of the study was to develop a sound, acceptable water development plan.

It was concluded that development of tributary reservoirs would exceed (in some cases) the payment capacity of local agricultural areas. In addition, tributary developments to reduce floodflows were not as economically feasible as a main stem reservoir at Iron Canyon above Red Bluff. This reservoir project had been investigated by various State and Federal agencies since the early 1900s.

20. California Department of Water Resources 1962. Sacramento River water pollution survey. Bulletin No. 111.

The objectives of this survey were to: (1) Determine base-line quality conditions for the Sacramento River from Shasta Dam to Mayberry Slough; (2) determine sources of water quality degradation at that time; (3) establish a water quality monitoring program; and (4) recommend future studies and water quality management practices for the Sacramento River. The study was conducted from April 1960 through June 1961.

This is a summary of information that is presented in four separate appendices (under separate covers).

#### Appendix A - Hydrography, hydrology and water utilization

Uses of Sacramento River water are discussed including domestic, irrigation and industrial water supplies; electrical power generation; recreation; fish and wildlife propagation; navigation; salinity repulsion in the delta; disposal of wastes and flood control. Estimates are presented for 1999 urban and irrigation water demands. Sources of pollution are also discussed, such as sewage, industrial and agricultural wastes.

#### Appendix B - Water quality

Water temperatures decrease in the winter as the Sacramento River moves downstream from Keswick Reservoir. The opposite occurs during the rest of the year with the temperature increasing to Sacramento and then decreasing slightly at the

confluence with the American River.

The river had a mean pH of 7.3 with tributaries and agricultural return waters being somewhat more alkaline. Spring Creek above Keswick has extremely acid waters but is quickly buffered by the river.

Suspended solids, turbidity, and color are low at Keswick Reservoir but increase downstream due to irrigation returns, waste discharges, and algal production in the middle and lower reaches.

Specific conductance (EC) and total dissolved solids are lower in the spring months due to snow melt. During the balance of the year irrigation return water increases the EC. The EC decreases in the river with the inflow of the Feather and American Rivers. In general, variations in constituent minerals followed variations in EC.

Dissolved oxygen (DO) decreased with movement downstream. An oxygen sag (51-69 percent saturation) was reported below Sacramento due to organic waste discharge by the city.

#### Appendix C - Public health aspects

Bacteriological quality was adversely impacted by nondisinfected sewage, agricultural and industrial discharges. Highest coliform concentrations occurred at stations below cities and during low-flow conditions. Some city water supplies exceeded drinking water standards even after treatment.

The river met all drinking water standards for chemical constituents except in Redding during storm periods when iron and manganese content was above standards.

Plankton numbers increased with movement downstream. Diatoms predominated, though the green alga *Ankistrodesmus* was numerous in mid-summer.

#### Appendix D - Benthic biology

Over 150 species of animals representing 10 phyla were collected from 29 stations. The dominant organisms were oligochaetes (worms), dipterans (flies) and trichopterans (caddisflies).

The river was divided into four major environments. The upper reach (above mile 229) was characterized by benthic invertebrates that inhabit clean, fast-flowing water such as caddisflies, mayflies, stoneflies, true flies and oligochaete worms. This reach had the greatest species richness and density of organisms.

The lower reach (mile 18.8 to Suisun Bay) was the next most productive with primarily clams, amphipods, oligochaetes and midge larvae present.

The two middle reaches were the least productive with most of the organisms being oligochaetes, midge larvae, and clams.

21. California Department of Water Resources 1964. Colusa basin investigation.

The Colusa Basin is principally an agricultural area, but also is valuable as wildlife habitat. The soil is of poor quality both in texture and alkalinity restricting crops to primarily rice and pasture. Frequent flooding occurs from tributary runoff and precipitation within the basin.

Water quality problems were identified in some areas due to leaching from alkali soils.

Recreation in the form of pheasant and waterfowl hunting is one of the principal resources identified.

Possible flood and drainage control problems are addressed. A cost-benefit analysis showed that none of the possible projects to alleviate problems were justifiable. Watershed management and some levee work were identified as possible economic means to reduce flood hazards.

22. California Department of Water Resources 1969. Clear Creek temperature study.

This report was designed to study the temperature gradient of Clear Creek from Whiskeytown Dam to the Sacramento River. Water temperatures were monitored with five thermographs.

A discharge record from May through September 1969 is presented. An average of 50 cfs was released during 1969. From mid-June to September nearly all the flow is from releases. Water leaving Whiskeytown Dam ranged from 52 to 55°F with daily fluctuations seldom exceeding 1°F. As the water moves downstream it is warmed and daily fluctuations increase. The rate of temperature increase is less than 1°F per mile for the initial 11.5 miles and 2°F per mile for the final 5.5 miles with an average of 1.5°F/mile overall.

23. California Department of Water Resources 1969. Preproject report on Sacramento River.

This is a summary of activities undertaken and information gathered by Northern District personnel as part of the District's services to the Operations Water Quality Control Program.

The report presents travel times for the Sacramento River from just below the Red Bluff Diversion Dam to the confluence with the Feather River. Travel times were determined for flows from 2,000 to 25,000 cfs. It was recommended that travel times also be developed for tributary streams.

24. California Department of Water Resources 1969. Squaw Creek copper investigation. Water Quality and Biology Section Report.

Little Squaw Creek discharged an estimated 100,000 pounds or more of copper into Shasta Reservoir per year. Fifty to 70 percent of the total copper comes from mine drainage (Balaklala and Keystone Mines). The highest concentration of copper was found from the Shasta King mine but the discharge is very minor.

The amount of copper discharged was directly related to runoff. During the summer concentrations increased as the flow receded. However, the actual amount of copper discharged was reduced.

The amount of copper discharged in 1968-69 increased from that in 1939. However, more work is needed to establish any trends.

Five possible solutions are presented for reducing the acid mine pollution: 1) Reroute stream channels to prevent runoff from flowing through the mines; 2) maintenance of the mines to prevent ponded water; 3) sealing of the mines to prevent oxidation of the ores; 4) ponding the mine drainage to allow the copper to precipitate prior to discharge into the stream; and 5) cribbing areas to reduce erosion.

25. California Department of Water Resources 1969. Temperature studies in Clear Creek.

This report presents temperature information collected by thermographs at Clear Creek near Highway 99, the Sacramento River above Clear Creek, the Sacramento River at the Red Bluff Diversion Dam and Battle Creek at Coleman Fish hatchery.

Clear Creek and Battle Creek showed substantially higher summer temperatures than did the Sacramento River. The river at the Red Bluff Diversion Dam showed significantly higher temperatures than the river above Clear Creek. It was concluded that the higher temperature inflows of tributary streams caused the increased temperature at the diversion dam.

A recent report suggests that the increased temperature at the diversion dam is due to direct warming of the river and reservoir behind the dam.

26. California Department of Water Resources 1970. Sacramento River water quality study, 1969-70. Part I: Historic and estimated 1990 electrical

conductivity in the Sacramento River system. Memorandum Report.

This study was conducted in two parts. Part I, presented here, involved the development of a water quality computer model to evaluate future electrical conductivity (EC) in the Sacramento River system in the year 1990. Conductivity was selected as the water quality parameter for modeling because there was more historical EC data available, EC is a conservative constituent of water, and EC can be used to estimate constituents, particularly total dissolved mineral concentration.

The model is a computational method for estimating monthly flow-weighted mean EC for 12 reaches on the Sacramento River above Freeport. Flow and EC data on diversions and inflows include natural flow, agricultural drainage, and municipal and industrial waste discharges.

The more highly regulated river flows projected for 1990 will tend to smooth out EC fluctuations and reduce extreme values. Flow-rated EC's for 1990 will increase over historic EC's due to increased water use in the valley. Total dissolved mineral concentrations will remain of excellent quality and total dissolved solids will increase, but the extremes will be of a lesser magnitude.

27. California Department of Water Resources 1970. Sacramento River water quality study, 1969-70. Part II: Present water quality. Memorandum Report.

This was a one-year study to determine the impact of future expansion of irrigated agriculture on the quality of water in the Sacramento River. It was conducted from August 1969 through June 1970 to determine the water quality of the river and agricultural drains.

Sixteen stations (four on the Sacramento River, one on the Feather River, and the remainder on drains, sloughs or canals) were sampled twice each month. The data collected include date, time, temperature, flow, pH, electrical conductivity, turbidity, ammonia plus organic nitrogen, nitrate, orthophosphate, and total phosphorus.

In early January of 1970, a series of storms caused heavy rainfall and resulted in the flooding of many lowland areas. Conductivity was low in the upper reach and increased as the river flowed down the valley. This trend is generally interrupted by inflowing low EC Feather and American River waters. Significant decreases in EC occurred during the January floods.

Waters discharged from tributary drains showed higher EC than the river. However, EC patterns for each drain did not display strong similarities.

Turbidity levels in the river are very responsive to rainfall and flow conditions. Highest values corresponded to January flooding.

Lowest turbidities were found below Keswick Dam due to dilution provided by upstream storage. Highest values occurred above the Colusa Basin Drain. Levels at Elkhorn and Freeport were much lower due to dilution from the American and Feather Rivers. The turbidity levels were generally higher in the drains than in the river.

Total nutrient values showed the same trends as turbidity in the river, except that the highest values were found at the Freeport station. This increased nutrient level was due to industrial and municipal loading by Sacramento. Nutrient values in the drains were highly variable but were generally greater than those found in the river.

28. California Department of Water Resources 1971. Mathematical simulation of salinity in the Sacramento River system. Bulletin No. 156.

This model simulates mathematically the monthly flow-weighted mean electrical conductivity for 12 reaches in the Sacramento River system. Using available flow and EC data, the model was developed around three general types of flow: unregulated tributary inflow; reservoir releases; and valley floor accretions and depletions (storm-water runoff, irrigation return flow, municipal and industrial waste discharges, diversions of streamflow for beneficial use, weir spills, and unmeasured inflows and losses).

Salt loading in tons, corresponding rates of streamflow in acre-feet, and flow-weighted EC in micromhos were included as model outputs for each reach and each time period. The model was verified by comparing computed EC values with prototype values at each station.

The model was used to estimate the probable future EC at each station under a projected 1990 level of development. Results showed an increase in flow-weighted average EC, but no monthly values were great enough to threaten beneficial uses.

29. California Department of Water Resources 1972. Flood control project maintenance and repair, 1971 inspection report. Bulletin No. 149-71.

In 1971, flood control levees extending 1,540 miles were maintained under cooperative State and Federal agreements in the Sacramento and San Joaquin Valleys and in Lake and Placer Counties. Twice in 1971, Department specialists inspected and classified the quality of levee maintenance performed by maintaining agencies. This bulletin reports the 1971 ratings, the method of rating, and proper maintenance procedures. It also reports levee construction by the U.S. Army Corps of Engineers, channel maintenance, applications for levee encroachments, and condition of the flood control project structures. Maps locate project levees and local maintenance agencies.

30. California Department of Water Resources 1973. Sacramento River supplemental water quality data.

The study area included the entire Sacramento Valley from Freeport north. The primary objective was to provide environmental planning information to evaluate agricultural discharges into the Sacramento River. The study was designed to expand existing data on nutrients, to obtain additional data on pesticides in agricultural flows, and to determine the presence of mercury.

The data were collected from 21 stations including the river and several drains. Samples were collected quarterly (March, July, September and November), with pesticides being analyzed in July and November. The data collected include: temperature, flow, pH, EC, turbidity, ammonia plus organic nitrogen, nitrate, orthophosphate, total phosphorus, pesticides, and mercury.

Conductivity of the river is generally low in the upper reaches and increases in the lower reaches. However, periodic decreases occur where major flows of low EC waters enter the river (i.e. Feather and American Rivers). Agricultural drain waters were generally higher in EC.

Turbidity in the river was very responsive to rainfall and flow conditions (increasing with increased flow).

Nutrient levels were lowest at Keswick Dam and increased as the river moved downstream. Lower nutrient levels were found below the confluence of the Feather River due to dilution. Nutrient concentrations increased below Sacramento which was probably a result of industrial and municipal loading. The drains were quite variable but nutrient levels were usually greater than in the river.

Pesticide concentrations were quite low with only one sample exceeding 1 ppb. Similarly, only one sample contained any measurable mercury, but was less than 1 ppb.

31. California Department of Water Resources 1976. Development and implementation of a coordinated statewide monitoring program. Task III: Primary surface water quality monitoring network design. Special Report. Division of Planning.

This report describes the designation of a statewide primary network for surface water quality monitoring including station location, parameters and frequency of data collection to satisfy the needs of the State as well as Federal regulations. The proposal included 72 stations on 28 streams and 20 stations on eight lakes.

Rationale for selection of the stations are included with a description of the location

and any historical data are identified. Recommendations were made for operation of the network and reporting and storing the results.

32. California Department of Water Resources 1979. Letter to Mr. D. E. Kienlen, Sacramento Valley Water Quality Committee.

Data were collected on 15 stations in the Sacramento Valley from October 1, 1977 to December 31, 1978. Included were flows, temperature, pH, dissolved oxygen (DO), specific conductance (EC), suspended solids, and total dissolved solids in tabular forms. Also included were graphical representations of data since January 1974 for discharge, EC, DO, temperature and suspended solids.

Suspended solids concentrations for early 1978 exceeded those found in the past (by as much as five times), at all but one station. The increase was attributed to heavy accumulation of sediments in the drought years, with flushing during early 1978.

33. California Department of Water Resources 1979. Observations of Sacramento River bank erosion, 1977-78.

Between 1952 and 1977, native vegetation in the Sacramento River's riparian zone from Redding to Colusa decreased by 14 percent, while agricultural use increased by 12 percent and urban use increased 3 percent. The soils of the river are subject to erosion which is of major concern to property owners and public agencies.

The Department began the study in January 1977 to compare erosion to flow rates. The report documents bank recession, general trends, and conclusions based on field data and site observations.

Six sites were studied between Stony Creek and Colusa. The square footage of bank eroded at each site was determined.

Many factors are identified that add to bank erosion potential including river flow and duration, bank curvature, soil composition, depth of the water, land use, and slope of the ground toward the river.

Only a single site exhibited significant erosion during low flows. This was attributable to a high percentage of sand in the soil, the current being almost perpendicular to the bank, and the thalweg being adjacent to the bank. Three other sites showed evidence of slope slumping and undercutting during low flows.

High flows were much more conducive to erosion. Erosion was highly variable at each site. The data suggested that bank erosion may increase exponentially with flow. However, this could not be proven statistically because of a lack of data.

34. California Department of Water Resources 1982. Clear Creek study.

This report summarizes environmental data to supplement engineering and fisheries investigations. The study was part of an effort to determine the feasibility of fisheries enhancement on Clear Creek. Descriptions and locations of 16 stations on Clear Creek and Whiskeytown Reservoir are included.

Nutrient and mineral levels were low but significant levels of some heavy metals were found. The relatively low hardness of the water may increase the toxicity of these metals.

Four temperature recorders were installed in Clear Creek (three in late May 1981 and one in early September 1981). Temperatures peaked in August. The overall heating rate was 1.45°F/mile with the greatest rate in the lower reach from Placer Road to Little Mill Road (2.33°F/mile). Stream temperatures reached equilibrium with ambient air temperatures below Little Mill Road. Higher flow releases resulted in higher dissolved oxygen and lower temperatures even though highest air temperatures occurred at this time.

Conditions were within the optimum range for trout and salmon survival at a discharge of 300 cfs.

Turbidities were checked daily from February 16, 1982 to August 31, 1982. The maximum value was 43 FIU. Runoff from tributaries below Whiskeytown Dam caused turbidity spikes that were relatively short lived.

Typical diurnal patterns for water quality parameters (dissolved oxygen, temperature, and pH) were observed for a continuous 48-hour study in September 1981.

Benthic macroinvertebrates, collected on May 21, 1982, showed rather low abundance and species richness. Chironomids and simuliids dominated.

Temperature and dissolved oxygen profiles for the reservoir showed typical thermal stratification during the summer, with erosion of the thermocline by early fall.

Two previous DWR reports on Clear Creek are presented in the appendix and are discussed.

35. California Department of Water Resources 1983. Land use change in the Sacramento River riparian zone, Redding to Colusa. A second update: 1977-1982.

This was the third in a series of reports on land use changes along the Sacramento River. The first report found that riparian vegetation along the Sacramento River was

reduced by 8,900 acres from 1952 to 1972, while orchard lands increased by over 13,000 acres.

The second report found an additional loss of 950 acres of riparian vegetation and a gain of 2,900 acres of orchard land from 1972 to 1977. In addition, 912 acres of prime high terrace soils were lost to bank erosion (gains were not recorded).

During the five years from 1977 to 1982, high terrace riparian vegetation did not change, orchard lands increased by 810 acres, riparian lands under protected status increased to over 2,100 acres, low terrace riparian vegetation diminished by 650 acres, and erosional 1088 of high terrace prime soils was offset by natural soil-building processes that created an equal or greater amount of prime high terrace soils.

36. California Department of Water Resources 1983. Quantification of acid and heavy metal discharges from mine portals and dumps at Balaklala, Keystone and Shasta King Mines.

This report presents monitoring results of wastes from mines in the West Squaw Creek drainage. Monitoring was conducted from November 1982 through April 1983. Twelve sites were selected in November and two sites were added in March.

Parameters monitored included flow, temperature, pH, dissolved oxygen, turbidity, sulfate, cadmium, copper, iron and zinc on a monthly basis. December parameters included additional metal and mineral analyses.

Data from the sealed Weil portal showed very little change in quality or flow during the study period.

Concentrations of metals in West Squaw Creek during this study were generally lower than those reported in 1980 and 1981.

The movement of copper, zinc, cadmium and iron was calculated for each station on each date and mass balances were then produced. Mass balances for cadmium were seldom meaningful under high flows since the concentration would drop below detection levels.

About 90 percent of the metal outflow from mine portals was coming from the Balaklala Portal in October. Less than 42 percent reached West Squaw Creek below the lowest mine (Shasta King Dumps). About half the iron was dropping out between there and the mouth of West Squaw Creek.

During higher flows the Balaklala Portal was still the single largest source of metals. There was an apparent inflow of metals from storage in subsurface fracture systems

and stream channels during these periods since the outflow of iron at the mouth of West Squaw Creek was greater than that below the Shasta King Dumps.

37. California Office of Planning and Research 1978. The California water atlas. Sacramento.

The atlas was developed to provide the average citizen with a single volume point of access to understanding how water works in California. It treats every aspect of water supply, delivery, and use in California. Other topics addressed include the nature of the water environment, the changes mankind has made in that environment, the history of water development, the operation of major natural and artificial water systems of today, the relationship of water pricing to water consumption, the uses of water in industry, recreation, and energy development, the problems of water quality, and the current and emerging questions of water policy for the future.

38. California Regional Water Quality Control Board 1978. Waste discharge requirements for SCM Corporation and M. and B. Mining Service Limited, Bully Hill and Rising Star Mines, Shasta County. Central Valley Region. Order No. 78-155.

This was an order to the mine owners to reduce to the maximum extent possible, discharge from mine adits by minimizing surface water inflow into the mines. Also, they were to reduce to a maximum extent acid and heavy metal drainage from waste piles, ore dumps, exposed ore bodies and other non-point sources .

39. California Regional Water Quality Control Board 1978. Waste discharge requirements for Silver King Mines Inc., Balaklala, Keystone, and Shasta King Mines, Shasta County. Central Valley Region. Order No. 78-153.

Same as previous reference.

40. California State Water Resources Control Board 1979. Toxic substances monitoring program, 1976-1977. Water Quality Monitoring Report No. 79-20.

Benthic organisms (bivalves, caddisflies and crayfish) and fish were collected and analyzed for metals and organic compounds. Invertebrate flesh and cross sections of fish including tissue and kidney (minus large bones) were used in the analyses. Both predatory and forage fish were collected. The samples were collected from several primary network streams in California.

Each parameter is discussed with respect to where it exceeds various criteria, the potential source of the problem, where it accumulates in the organism and whether or not it is bio-concentrated. Some parameters included: arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc, DDT and its metabolites, polychlorinated biphenyls

and Dieldran.

Mercury concentrations in forage and predator fish exceeded U. S. Food and Drug Administration criteria in Cache Creek (1976 and 1977), the Sacramento River (1976 predators only) and the Yuba River (1976 and 1977)

41. California State Water Resources Control Board 1980. Toxic substances monitoring program, 1979. Water Quality Monitoring Report No. 80-6.

Benthic invertebrates (clams and crayfish) and predatory fish were collected from 28 primary network streams between March and November 1979. All collections were made at low base flow. Clam flesh, crayfish tail flesh and fish livers were analyzed for metals, and fish flesh for mercury. Both invertebrates and fish flesh were also analyzed for 55 synthetic organic compounds, most of which were pesticides. Composite samples of six or more organisms were analyzed when possible.

U. S. Food and Drug Administration tolerance levels were never exceeded. In the biota of some streams, however, concentrations of mercury, chlordane, DDT and its metabolites, toxaphene, and polychlorinated biphenyls (PCBs) exceeded recommended guidelines for protection of fish and wildlife.

42. Central Valley Regional Water Pollution Control Board 1955. Water pollution study, Sacramento River watershed.

The drainage area includes the Goose Lake Basin and has an area of about 26,960 square miles. The main valley floor contains 5,000 square miles extending from Red Bluff to Suisan Bay. The mean annual runoff is about 22,390,000 acre-feet which is slightly less than 32 percent of all California streams.

Major beneficial uses of the Sacramento River include municipal, domestic and industrial water supply; irrigation; power generation; salinity control; navigation; fish propagation; flood control; and recreation.

Information is presented about severed and unsevered communities existing at that time. Identified as accounting for 90 percent of the industrial waste disposal are food processing, mining, and lumbering.

The article is comprised of five chapters including; Policy Program and Planning; Historical Description of the Basin; Physical Features of the Sacramento Valley; Water Supply and Use in the Sacramento Valley; and Waste Disposal in the Basin. Also included is a summary of plans for water resources development in the Sacramento Valley.

43. Finlayson, B. J., and D. Wilson 1979. Acid mine waste, how it affects king

salmon in the upper Sacramento River. Outdoor Calif., Cal. Fish and Game 40(6): 8-12.

An overview of the acid mine waste problem of Spring Creek is presented. Migration routes and life histories of king salmon are also presented.

Fish that migrate beyond Cottonwood Creek run the risk of acid mine poisoning from the Spring Creek drainage. Over the past 20 years many kills of greater than 1,000 fish occurred, and major kills of greater than 10,000 fish occurred in 1955, 1963 and 1964.

A brief history is presented with measures to alleviate the problems that mining created in the Spring Creek drainage.

44. Finlayson, B. J., and K. M. Verrue 1980. Safe zinc and copper levels for chinook salmon, *Oncorhynchus tshawytscha*, in the upper Sacramento River, California. Cal. Fish and Game 66(2): 68-82.

Acid mine waste from Spring Creek drainage has caused numerous kills of salmonid fishes in the upper Sacramento River between Keswick Reservoir and Cottonwood Creek. Combined toxicities of Zn and Cu to chinook salmon eggs, alevins, and swim-up fry were reported in this paper.

From 1963 to 1978, acid mine waste collected in Spring Creek Reservoir was metered into Keswick Reservoir. In 1978, new release schedules were implemented, using Cu-to-Zn as criteria instead of just Cu concentrations.

The objectives of this paper were to gather toxicological information on Cu-to-Zn ratios and to evaluate release schedules employed since 1978. Three Cu-to-Zn ratio (1:3, 1:6, 1:11) stock solutions were used in chronic (83-d) and acute (96-h) toxicity tests (continual-flow).

Mortalities of eggs and alevins for the total 83-d exposures as well as unexposed 90-day-old fry increased with increased total and dissolved Zn and Cu concentrations. Mortalities of controls were minimal. All Cu-to-Zn ratio solutions produced 83-d old fry which had lower mean weights and lengths than control fry.

Swim-up fry at the end of 83-d exposures were more tolerant to Zn and Cu in the 1:3 ratio than previously unexposed fry in the 96-h exposures, almost as tolerant in the 1:6 ratio, and less tolerant in the 1:11 Cu-to-Zn ratio. This may indicate that chinook salmon were able to acclimate to Cu with relatively low amounts of Zn present, but acclimating to Zn with less relative amounts of Cu present was not possible.

In all tests, the toxicities of Zn and Cu in combined solutions were "accumulative". Fish became more tolerant of Zn as Cu concentrations decreased. Copper

cementation plants, which could result in ratios as low as 1:12, even during dry periods, are warranted in the Spring Creek drainage.

Chinook salmon eggs were more tolerant than alevins and fry to Zn and Cu concentrations in 1:6 and 1:11 ratios. Lethal level tests indicate that swim-up fry of chinook salmon are probably the most sensitive life-history stage to Zn and Cu. Safe levels should be based on this life-history stage.

Based on these toxicity tests, safe levels for Zn and Cu of 86 and 11 ug/L, respectively, should approximate the maximum acceptable toxicant concentrations (MATC). However, even lower Cu concentrations have been reported to have an effect on anadromous salmonids, including a reduction in the percentages of downstream yearly migrations.

45. Finlayson, B. J., and S. H. Ashuckian 1979. Safe zinc and copper levels from the Spring Creek drainage for steelhead trout in the upper Sacramento River, California. Cal. Fish and Game 65(2): 80-99.

Acid mine discharges in the Spring Creek drainage, collecting behind the Spring Creek Diversion Dam, contribute large quantities of toxic zinc and copper to the upper Sacramento River. Ratios of copper to zinc for the Spring Creek Diversion Dam discharge fluctuate between 1:2 during storm periods and 1:8 during dry periods. Source control and treatment of the waste for copper removal would result in copper-to-zinc ratios of 1:12 or less in the future. Since the flows into the river of both the waste and the "dilution water from Shasta Lake can be controlled, dilution factors which will provide for the complete protection of salmonids in the Sacramento River need to be determined and implemented. To determine these factors, long-term (60-d) and short-term (96-h) bioassays were conducted with the waste on steelhead trout (*Salmo gairdneri*) eggs, alevins and swim-up fry.

The bioassays indicated that eggs were more resistant than alevins and fry to solutions containing both zinc and copper, while solutions containing only zinc affected all stages equally. At the lower copper to zinc ratio of 1:12, copper was absent in solution and toxicity was attributable to zinc alone, while at the higher waste ratio of 1:4, copper was present in sufficient quantities to increase the toxicity of the waste. The incipient lethal levels (10 percent mortality) for the period from eggs-to-fry were 0.12 mg/L Zn at the lower waste ratio, and 0.10 mg/L Zn and 0.011 mg/L Cu at the higher waste ratio. The incipient lethal level of control fry (those which had not been previously exposed to the waste) was 0.03 mg/L Zn. The presence of aluminum and iron in the waste apparently did not affect the toxicity of either zinc or copper. Safe levels of zinc and copper for steelhead trout are below 0.03 mg/L and 0.01 mg/L, respectively.

46. Glenn-Colusa Irrigation District. Water measurement program for 1975 1976.

This is a record of operations of the Glenn-Colusa Irrigation District for 1975. It is an accounting of water uses in the district and a comparison with the prior nine years. Some basic water quality data are presented (i.e. temperature and conductivity). The report is primarily a presentation of data in tabular and graphic form with only four pages of text.

47. Hayes, S. P.; A. W. Knight; D. E. Bayer; and G. R. Sanford 1978. The effects of irrigation return water on aquatic plants (Periphyton) in the Sacramento River at Knights Landing, California. Water Resources Center. Contribution No. 167. U. C. Davis.

The characteristics of irrigation return water from the Glenn-Colusa Irrigation District (GCID) and its impact on Sacramento River water were studied for three summer irrigation seasons. Stations were set up above, in and below the Colusa Basin Drain (CBD) at Knights Landing. Water samples were collected and analyzed for levels of suspended matter, turbidity, conductivity, major cation and anion concentrations, temperature and pH (abiotic parameters).

Biotic parameters (densities of dominant diatoms, total diatom density, chlorophyll a, b, and c, and organic matter) were obtained from periphyton communities harvested on glass substrates.

The CBD water was found to differ significantly from the Sacramento River and to have an impact on the river below the CBD outfall. Two major patterns were apparent. Abiotic parameters (except pH in 1975) were higher in the CBD than in the Sacramento River and caused higher values in the river below the outfall, which gradually decreased downstream to a level slightly above the levels found above the outfall. Biotic parameters showed the opposite trend, with significantly lower measurements in the CBD than in the river above the outfall, with little effect on downstream stations in the Sacramento River.

The impact of CBD water on the river occurred for a considerable distance below its outfall. Only at a station 1990 meters below the outfall did the abiotic parameters return to near above outfall levels. Since some biotic factors peaked in the below outfall stations, CBD water may have enriched the river.

48. Hazel, C. R., and S. J. Meith 1970. Bioassay of king salmon eggs and Sacramento River fry in copper solutions. Cal. Fish and Game 56(2)

Flowing water bioassays of chinook salmon eggs and fry in a copper solution indicated that eggs are more resistant to the toxic effects of copper than fry. Copper concentrations of 0.08 mg/L did not noticeably affect the hatching success of eyed eggs, but concentrations as great 0.4 mg/L were acutely toxic to fry and concentrations

of 0.02 mg/L caused increased mortality and inhibited growth.

49. Heiman, D. R. 1980. Inspection - Little Backbone Creek. Water Quality Control Board Memorandum to U.V. Industries.

An inspection of Little Backbone Creek was made on June 27, 1980. Ten to 20 dead rainbow trout were observed at the confluence with Lake Shasta.

Water samples were taken from the Mammoth Mine drainage, above the Mammoth Mine drainage, and above the confluence with Lake Shasta. Sample analyses indicated that drainage from the Mammoth Mine contributed 90 percent of the copper and 96 percent of the zinc in Little Backbone Creek.

50. Herman, D. R. 1982. Inspection at Mammoth Mine. Water Resources Control Board Memorandum to J. C. Pedri.

An inspection of Mammoth Mine was made on February 25, 1982. A seal had been placed in the main Mammoth portal in December 1981. There was no leakage around the seal. Water that had backed up behind the seal was now exiting the Friday-Lowdan Portal and heavy metal concentrations of the effluent had greatly increased.

Samples taken from Little Backbone Creek had shown much improvement in heavy metal concentrations and fish kills were no longer expected. However, since there was an increased discharge from the Friday-Lowden Portal, it would be necessary to monitor Shoemaker Gulch at its confluence with Lake Shasta for fish kills.

51. Hunt, E. G. 1964. Fish population studies in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FW1R-1.

The objective was to determine the effects on fish populations of pesticide residue drainage from agricultural lands. Catfish were collected from three major agricultural drains (Colusa Basin Drain, the Sutter Bypass and the San Joaquin River) and analyzed for pesticide residue (DDT, DDD, DDE, Endrin and Dieldrin). The highest concentrations were found in the Colusa Basin Drain. Therefore, this drain was selected for further detailed study of the chronic effect of pesticides on fish and other aquatic animals.

52. Hunt, E. G. 1965. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FW1R-2.

Fish (white and channel catfish and black bullheads), other aquatic animals (mallard duck, pied billed grebe, and Pacific pond turtle), water samples, bottom mud samples

and suspended solids were collected and analyzed to determine the degree of pesticide contamination in the Colusa Drain. Samples were collected from two stations in December 1964 and March, April, and May 1965. Low residues were found in the water, suspended solids, and bottom mud. Analytical results were not available for the fish except one black bullhead with low residues. The Pacific pond turtle had high residues of DDE in its fat.

53. Bunt, E. G. 1966. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal Fw1r-3.

Twelve fish samples, six clam samples and four water samples were collected and analyzed for pesticide residue. Eleven fish flesh samples (white and channel catfish) were collected in May 1965. DDT found in catfish in 1965 ranged from 5 to 50 ppm (based on extracted fat) and 20 to 1,070 ppm in 1964. This reduction may have been a reflection in changing agricultural practices since DDT use was decreased drastically in 1964.

Three species of clams were collected (*Anodonta nuttaliana*, *Gonidea angulata* and *Corbicula fluminea*). *Corbicula* was found in abundance and showed the highest residue values. High values were found in August 1965 reflecting high summer pesticide use. Fish make up the main food item of catfish in the drain. This may be a reflection of a shortage of benthic organisms (except clams) that was found in 1965. It was recommended that further studies are needed on the effects of pesticide residues on benthic productivity.

Preliminary tests were made of the effects of the organo-phosphate insecticide Dursban on green sunfish in rice fields when applied at mosquito control levels (0.025 and 0.05 pounds/ac). The first test (conducted in May), was inconclusive since the water temperature reached 97°F, which may have caused the fish mortality. A second test (conducted in June) resulted in the death of all the fish when Dursban was applied at 0.05 pounds/ac, and the death of 2 of 30 fish when applied at 0.025 pounds/ac. It was concluded that Dursban should not be applied at rates above 0.025 pounds/ac.

54. Hunt, E. G. 1967. Studies of pesticide contamination of aquatic organisms in agricultural drains. Pesticides investigations. Calif. Dept. Fish and Game. Cal FW1R-4.

Four white catfish and one channel catfish were collected from the Colusa Basin Drain during July and December 1966. Flesh samples were analyzed for chlorinated hydrocarbon residues (DDT, DDD, DDE, Aldrin, and Kelthane) and percent fat.

Pesticide levels in the fish were much higher than the previous year and approached

the levels reported in the first study (1964). Aldrin residues were found in all of the fish but were considered questionable since Aldrin is changed to Dieldrin in biological systems. The project was discontinued because of a lack of manpower.

55. Institute of Paper Chemistry 1968. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1967. Report 5 to Kimberly-Clark Corporation.

This was the fifth in a series of yearly studies of macroinvertebrates inhabiting riffles in the Sacramento River near Anderson, California. The studies were initiated in 1962 prior to completion of the Kimberly-Clark paper mill. Benthic macroinvertebrates were used as indicators of the general health and well being of the river.

Eight stations were sampled to measure density, diversity and species composition of the macrobenthos. Two stations above the mill served as controls. A significant increase in population density was observed below the mill outfall, which was probably related to stability of the stream bottom rather than to water quality. Stations above the outfall had small clean stones without vegetative growth, while stations below had more vegetation on larger more permanent stones.

The overall density of intolerant or sensitive invertebrates had decreased from previous years. This reduction, however, was considered a result of natural fluctuations.

Increased growths of blue-green algae were noted both above and below the outfall.

56. Institute of Paper Chemistry 1970. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1969. Report 6 to Kimberly-Clark Corporation.

This paper presents results of both field and laboratory investigations which represent a measurement of the character of the macrobenthos and, hence, the indicated water quality for a period of at least one year prior to early October 1969.

Each of nine stations was concluded to be biologically balanced. Three were considered to be eutrophied due to heavy growths of *Fontinalis*, an aquatic moss.

Due to the fact that these areas of increased growth of *Fontinalis* occurred only in areas that were subject to discharges from Kimberly-Clark Corporation's Shasta Division, it is possible that certain materials present in the effluent from the mill may have been responsible for the increased incidence of *Fontinalis*.

The increase in the amount of *Fontinalis* present did not seem to have a detrimental effect on the macrobenthos. However, it decreased the suitability of potential spawning sites for migratory salmonids in the Sacramento River. Spawning

previously took place in areas occupied by unusually large amounts of vegetation. No spawning activity was observed in 1969 in areas of heavy growths of *Fontinalis* and other aquatic vegetation.

57. Institute of Paper Chemistry 1971. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1970. Report 7 to Kimberly-Clark Corporation.

This paper was a result of both field and laboratory investigations and presents a measurement of the character of the macrobenthos and water quality for at least one year prior to early October 1970.

All nine stations were considered to be biologically balanced with normal macrobenthos character. Station 4C-1, which was about 0.6 miles downstream from the mill outfall, was studied for the second year in a row. Large accumulations of an aquatic moss, *Fontinalis*, were present and formed a thick, continuous mat upon the substrate of the river. Apparently, this growth was not detrimental to macroinvertebrate animal populations as density, diversity, and species composition was indicative of excellent and unimpaired conditions.

At station 4C-2, only 150 yards away and with the same hydrological conditions as 4C-1, there was little vegetative growth, and conditions were similar to control stations above the mill. No explanation is given for the differences between stations 4C-1 and 4C-2. However, it is pointed out that these observations refute the suggestion made in 1969 that mill waste is responsible for growth of *Fontinalis*. Overall, there was less river area affected by this growth in 1970 than in 1969. No explanation is given for an increased growth of the filamentous green algae *Cladophora* sp. found in 1970.

58. Institute of Paper Chemistry 1972. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1971. Report 1 to Simpson Lee Paper Company.

This was the eighth of a series of similar biological water quality studies of the Sacramento River in areas where it could be affected by discharges of treated kraft pulp from the former Kimberly-Clark Corporation (now the Simpson Lee Paper Company) located near Anderson, California.

Nine stations on the Sacramento River were sampled to measure density, diversity, and species composition of the macroinvertebrate bottom-dwelling fauna. A total of 13 genera were present in the study area. Fifty-four percent of all organisms found were intolerant or sensitive to environmental change.

Each of the nine stations was found to be biologically balanced and capable of supporting a great variety of organisms including intolerant or sensitive forms.

Station 4C-1, which is 0.1 mile downstream from the mill outfall, supported a profusion of aquatic vegetation including the aquatic moss *Hygrohypnum ochraceum* (formerly referred to as *Fontinalis sp.*). There was also a slight increase in very tolerant organisms, but there were very small numbers of these forms present.

At station 8, 20.8 miles downstream from the mill outfall, there was an increase in the amount of *Cladophora*, (a filamentous alga) present. The presence of *Cladophora* has been found to indicate a fertile condition associated with sanitary wastes in various rivers. This alga was also present at station 6, which is 7 miles downstream from the mill outfall. Sanitary wastes may be entering the Sacramento River from a housing development above station 6. No further effort was made to ascertain possible sources of waste.

This paper concludes that there was no adverse effect from the discharge of treated kraft pulp and paper wastes from the Anderson pulp mill in the Sacramento River during 1971.

59. Institute of Paper Chemistry 1973. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1972. Report 2 to Simpson Lee Paper Company.

This report was the ninth in a series studying the effects of Simpson Lee effluent on the Sacramento River benthic macroinvertebrate community. Macrobenthos samples were collected in October 1972 from nine stations.

Diversity ranged from 2.5 to 3.32, with densities from 441 to 1,693 organisms per square foot. Twenty-two to 27 species were identified per station.

Station 4C-2, 0.7 mile below the outfall, showed the most dramatic increase in density over the control stations. The major portion of the increase was from two caddisfly species (*Hydropsyche sp.* and *Brachycentrus americanus*). Diversity tended to decrease where the caddisfly numbers increased.

The intolerant segment of the community increased the most. Three stations at 0.7, 3.4, and 7.1 miles below the outfall were classified as enriched. Since species composition did not change and intolerant organisms increased, it was concluded that significant measurable environmental degradation had not occurred.

60. Institute of Paper Chemistry 1974. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1973. Report 3 to Simpson Lee Paper Company.

This report covers the tenth benthic macroinvertebrate study of the Sacramento River

near Anderson. Nine stations were sampled with station 4C-1 being dropped (0.6 miles below the outfall) and station 7 (15.0 miles below) being added.

Twenty-one to 29 taxa were found per station with diversity values ranging from 2.55 to 2.99. Very little change was observed in the number and kinds of taxa compared to previous studies.

The density of organisms increased immediately below the outfall and peaked at station 4C-2 (0.7 mile below the mill outfall) with tolerant midge larvae dominating. Intolerant forms also increased over the upstream stations. Biomass was also higher in the downstream stations. The increase in productivity may have partially been due to mill discharges into the river.

61. Institute of Paper Chemistry 1974. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1974. Report 4 to Simpson Lee Paper Company.

This was the eleventh benthic macroinvertebrate study designed to evaluate the impact of Kimberly-Clark's and Simpson Lee's effluent on the Sacramento River. Nine previous stations and one new station (China Rapids, 25.0 miles below the mill outfall) were sampled from during October 1974.

Species richness was more variable than in previous studies, however, diversity indices were not, ranging from 2.47-2.91. Redundancy values ranged from 0.266 to 0.451 and equitabilities from 0.310 to 0.687. The poorest species richness was found in the control stations above the mill outfall and tended to increase in the downstream stations. Three stations at 0.7, 7.1 and 15.0 miles below the mill outfall were classified as enriched.

62. Institute of Paper Chemistry 1976. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1975. Report 5 to Simpson Lee Paper Company.

This was the twelfth in a series of biological water quality studies conducted on the Sacramento River. Two new stations were added and a new numbering system was employed. Station locations and descriptions are presented.

Beginning in 1969, a gradual increase in density was noted in both control (above mill outfall) and test stations (below mill outfall). This may have been due to enrichment from agricultural practices or municipal and industrial nutrient loading.

Forty-nine species were identified overall, with an average of 22 per station. Redundancies ranged from 0.235 to 0.540. Diversity indices ranged from 2.0 to 3.2. A cluster analysis (modified Jaccard coefficient) revealed that all stations were similar

at the 0.97 level or better.

The community was numerically dominated by organisms intolerant to pollution, chiefly the caddisfly *Brachycentrus americanus*.

Consistent patterns were observed from year to year in the density of organisms at different stations, which may be due to habitat variations.

Major increases in density were observed at stations 5 miles above the outfall (control) and 0.7 and 25.0 miles below the outfall. These stations were described as enriched. The control station enrichment may have been from the City of Redding. Eight of 10 previously sampled stations showed density increases above their five-year average.

Biomass and numerical density followed the same pattern at nine of the twelve stations. However, stations at 0.5 and 7.1 miles below the mill outfall showed decreased density with increased biomass, while the station at 0.7 mile below the outfall showed the opposite trend. These discrepancies were attributed to either errors in handling or changes in the relative sizes of individuals.

63. Institute of Paper Chemistry 1977. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1976. Report 6 to Simpson Lee Paper Company.

Twelve stations were sampled for macroinvertebrates during October 1976 in this study (the thirteenth in a series).

Forty-four taxa were identified with as many as 30 taxa being found at a single station. Diversity indices ranged from 2.4 to 3.3, equitabilities ranged from 0.28 to 0.6, and redundancy from 0.289 to 0.485. Cluster analysis revealed that all 12 stations were similar at no lower than the 0.90 level.

The density of organisms at all stations was higher than in previous studies. Unusually low flows (nearly half the average) during this sampling period and the resultant concentration of organisms in a smaller area were identified as the probable cause for the increased density.

The average density of organisms at stations below the mill outfall was greater than the average density at the control stations. High and low benthic densities corresponded well with high and low current velocities, except at two stations where high velocity may have caused bottom scouring.

64. Institute of Paper Chemistry 1978. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1977. Report 7 to

Simpson Lee Paper Company.

This was the fourteenth in a series of benthic macroinvertebrate studies of the Sacramento River. Twelve stations were sampled between Redding and Red Bluff.

River flows were lowest in the 15-year history of the study due to drought conditions. Water temperatures were high due to releases from the epilimnion of Shasta Lake.

Forty-seven taxa were identified. Redundancy ranged from 0.31-0.46, equitability ranged from 0.32 to 0.54, and the Shannon-Weaver diversity ranged from 2.2 to 3.0. All stations were similar at or above the 0.92 level (Jaccard Similarity Index).

Species composition remained relatively stable from station to station but numerical density did not. With the exception of stations 5.0 and 1.1 miles above the mill outfall, densities were lower in 1977 than in 1976. However, the 1976 densities were significantly greater than average. The upper four stations in 1977 showed densities above the five-year average, while the two middle stations were close to average and the lower stations were below average. This pattern was partially explained by severely low flows and the decrease in substrate availability (several sample stations were above the water line).

There was a shift in dominance from the caddisfly *Brachycentrus americanus* to *Hydropsyche* sp. In 1975 both species were present in comparable numbers while in 1977 *Hydropsyche* sp. was 10 times more abundant at some stations. The surge in *Hydropsyche* sp. density was probably related to the drought which resulted in warmer temperatures, reduced flows, increased turbidity and increased concentrations of plankton. Some atypical peaks in community density may have resulted from the increase in *Hydropsyche* sp.

65. Institute of Paper Chemistry 1979. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1978. Report 8 to Simpson Lee Paper Company.

This was the fifteenth in a series of benthic macroinvertebrate studies begun in 1962 on the Sacramento River. Four stations were deleted so that eight stations were sampled in October 1978.

Forty-two taxa were identified including stoneflies, mayflies, caddisflies, midgeflies, beetles, amphipods, flatworms and segmented worms. In comparing taxa from 1978 and 1977, only 28 of 62 species were present in both studies which may be related to the previous two years of drought. The number of taxa per station averaged 22 and ranged from 18 to 26.

The Shannon-Weaver Diversity Index was lower than the previous five year average

and ranged from 1.58 to 2.59. This may have resulted from the increased dominance of the caddisfly *hydropsyche* sp. Equitabilities were also lower, ranging from 0.18 to 0.463, and redundancy ranged from 0.382 to 0.67. Cluster analysis showed all stations to be similar at greater than the 0.90 level.

An overall enrichment of the study area was apparent since there was a five-fold increase in the average density from 1962 to 1978 (400 per ft<sup>2</sup> and 1,900 ft<sup>2</sup>, respectively).

The shift in dominance from *Brachycentrus americanus* to *Hydropsyche* sp. was even more apparent at all stations, with *B. americanus* being described as a relic.

Data were insufficient to explain the long term increased density and shift in dominance but cultural eutrophication was strongly suspected.

66. Institute of Paper Chemistry 1981. A biological water quality study of the Sacramento River in the vicinity of Anderson, California - 1980. Report 9 to Simpson Lee Paper Company.

This is the sixteenth macroinvertebrate study in 18 years to determine if discharges from Simpson Lee have affected water quality in the Sacramento River.

Samples were collected in October 1980 with a surber sampler, and were sieved with a number 30 sieve and preserved in 10 percent formalin. Density and biomass were determined for nine stations (3 above and 6 below the mill outfall). The Shannon-Weaver Diversity Index, redundancy and equitability were also determined for each station. In addition, a cluster analysis (modified Jaccard coefficient) was performed to compare the similarity of stations.

A total of 37 taxa were collected, of which 14 were considered intolerant to pollution and 23 were facultative or tolerant types. An average of 9 intolerant and 11 facultative taxa per station were consistent with previous studies.

No meaningful differences between species richness above and below the mill were found. Species richness was also very close for 1980 and the five-year average.

Community density averaged slightly lower for the control stations above the outfall than the downstream stations. The average density for the entire stretch has been gradually increasing with periodic setbacks.

In 1980, a slight reversal in the shift in dominance of *Brachycentrus americanus* to *Symphitopsyche* sp. (*Hydropsyche* sp. in other reports) was observed. *Symphitopsyche* sp., however, was still strongly dominant.

Biomass differences were minor between control and downstream stations. Diversity index and equitability values were very consistent between stations and between 1980 and the 5-year average. The diversity values ranged from 2.10 to 2.82 and the equitability ranged from 0.29 to 0.52 in 1980.

All stations were found to be similar to each other at a very high level (0.97 or greater). Changes in density from station to station occurred according to a pattern established during past studies and were apparently related to river hydrology rather than water quality.

67. Johnson, R. K. 1981. The effect of mine drainage on benthic macroinvertebrates in Keswick Reservoir. Calif. State University, Chico. Master's Thesis.

The purpose of this study was to determine the effects of acid-mine drainage (Spring Creek) on the benthic macroinvertebrate community and to correlate any changes with existing physical-chemical and biological features present in Keswick Reservoir. A total of 96 samples were taken on six occasions from June to October 1980. Eight sampling stations were aligned longitudinally from above the confluence of Spring Creek to 1.85 kilometers below. Density, species richness, biomass, and diversity of macroinvertebrates decreased from above to below Spring Creek. Conversely, sediment concentrations of copper, zinc, and iron, as well as percent ash increased below the confluence. Significant relationships were found between sediment composition and macroinvertebrate community structure. Cluster analysis of the sampling stations clearly illustrated the division between polluted and non-polluted sections of the reservoir.

68. Leeds, Hill and Jewett 1957. Consulting Engineers, Los Angeles, California. Report to the State Water Pollution Control Board on control of pollution of Keswick Reservoir.

This article presents possible solutions for cleaning up mine tailings and mine seepage of heavy metals that enter Keswick Reservoir via Spring Creek.

Concentrations of dissolved metals were highest during low flows but the total quantity was much greater during freshets. With the advent of controlled releases from Shasta Dam, much higher concentrations of metallic salts occurred in Keswick Reservoir. Three main sources are identified including tailings along Slickrock Creek, tailings along Boulder and Flat Creek drainages and effluent from mines on Iron Mountain (the largest source).

Alternative solutions are discussed. Prevention at the source through removal of tailings or covering with an impervious blanket was impractical. Interception of pollutants by construction of a 10,000-20,000 acre/foot reservoir was considered economically infeasible. Chemical treatment was found physically but not

economically feasible. Disposal by dilution was the most feasible alternative and a plan was outlined. The plan included diversion of surface waters around tailings and deposits, sealing mines, construction of a pipeline to carry mine effluent to a 30 acre-foot regulating reservoir, and releasing the effluent with diffuser nozzles from a flexible pipe across the bottom of Keswick Reservoir.

69. Linn, J. D. 1965. Evaluation of the effects of Parathion used in rice leaf miner control on fish. Pesticides investigation. Calif. Dept. Fish and Game. Cal FWIR-2.

The study was conducted to determine if rice fields treated with Parathion at 0.1 pound/acre could be drained continuously during and after treatment without killing drainage ditch fish. The application was made in June 1965 and green sunfish were used as the test organisms. No mortality or intoxication symptoms were observed in the control and drainage ditch fish. Five of 20 fish died in the test field by the end of 96 hours.

The theoretical concentration of Parathion is 75 ppb when applied at 0.1 pound/acre in water 6 inches deep. This concentration falls in the lower portion of the toxicity curve for green sunfish ( $LC_{20}$ ). The conclusion was that at an application rate of 0.1 pound/acre, extensive fish kills would probably not occur, but the margin of safety would be small under certain conditions such as: (1) treatment of a field with water less than six inches deep; (2) when the drainage ditch had a low dilution factor; and (3) when conditions were most favorable for the spray reaching the water surface.

70. Lien, J. D. 1967. Experiments on the effects of field application of Hydrothol 191 on fish. Pesticides investigations surveillance of pesticide programs. Evaluation of pest control programs. Calif. Dept. Fish and Game. Cal FWIR-4.

The purpose was to assess the effects of the herbicide Hydrothol 191 on fish life. Five small canals were treated at a concentration of 0.5 ppm, one small canal at 1.0 ppm and one large canal at 3 ppm. In addition, one test was made with TD-499 at a concentration of 0.5 ppm. The experiments were conducted from July through September 1966. Observations were made on caged (green sunfish and carp) and uncaged fish.

No signs of tissue damage (gills, muscle, intestine, liver and kidney) were evident in one experiment at 0.5 ppm. The experiments indicated that Hydrothol 191 was not toxic to fish when applied at 0.5 and 1.0 ppm., but definitely was at 3.0 ppm. The experiment with TD-499 was inconclusive.

71. Lydon, P. A., and J. C. O'Brien 1974. Mines and mineral resources of Shasta County. California Division of Mines and Geology, County Report 6.

This is an excellent informational document on mining and mineral resources in Shasta County. Many mines in the Shasta/Keswick area are discussed under the copper mining section.

The history and geology of mining in the area is presented. Several mines (Afterthought, Balaklala, Bully Hill-Rising Star, Early Bird, Greenhorn, Iron Mountain, J.L.C., Mammoth, Shasta King, and Thompson) are discussed separately with respect to their location, mine characteristics (i.e. number of adits, and stopes, and distance of tunnels), geology, and history of ownership and production.

72. Metcalf and Eddy Engineers 1965. Program for the development of an operations plan for water quality control for the State Water Project.

This is an outline of a program to lead to an operations water quality control plan for the State Water Project. The report delineates starting and completion dates for elements of the program. The elements include studies on preproject water quality (both surface and ground water) from the headwaters of the Feather River, along various aqueducts to the storage and terminal reservoirs. Operating principals and inspection programs included studies to develop emergency and routine operating procedures, reporting procedures, and monitoring and recording networks.

73. Metcalf and Eddy Engineers 1966. Program for the development of biological control procedures for water quality control for the State Water Project.

This report provides guidelines for maintaining project water quality through controlling eutrophication by preventative measures. Emphasis was placed on prevention of the release of waste matters (solid or liquid, animal or human, raw or treated) into project waters. Finally, the report deals with a plan for implementing a program of biological control and surveillance.

74. Metcalf and Eddy Engineers 1970. A water quality operations plan for the State Water Project.

This report presents a water quality operations plan for the State Water Project that includes a list of water quality goals and constraints and recommendations for a monitoring network throughout the length of the project.

The monitoring network was set up to meet five goals: (1) to monitor water quality of delivery waters to contractors; (2) to monitor water quality of water entering storage facilities; (3) to record changes in stored water; (4) to monitor changes related to recreational uses; and (5) to determine the effect of the project on nonproject waters.

75. Mifkovic, C. S., and M. S. Peterson 1975. Environmental aspects - Sacramento

bank protection. J. Hydr. Div., Proc. Am. Soc. Civ. Eng. 101 (HY5)

Studies showed that bank protection could include environmental measures and could preserve environmental values from erosion. Reclamation of the Sacramento Valley included federal construction of a leveed flood control project. Erosion had threatened the integrity of the levee system and a program of revetment construction at critical sites was authorized in 1960. Early construction was on a least cost basis and seriously reduced riparian vegetation which supplies important wildlife habitat. Alternative revetment designs and construction procedures were developed to minimize adverse environmental effects.

76. Moffett, J. W. 1949. The first four years of king salmon maintenance below Shasta Dam, Sacramento River, California. Calif. Dept. Fish and Game. 35(2)

This report dealt primarily with a fisheries management plan for chinook salmon below Shasta Dam during the dam's first four years. Ecological changes in the river are also presented.

Due to control flow releases from the dam, summer water temperatures were lower than prior to dam construction. Heat stored in the reservoir water was influential in maintaining higher temperatures in the river long after climatic conditions would have normally cooled the water to less than 50°F. These temperature changes provide more optimum conditions for salmonids. Egg development and timing of seaward migration were accelerated due to warmer winter conditions.

Other effects of the reservoir are included. Fifty percent of anadromous salmonid spawning habitat was lost due to dam construction. Spawning gravels below the dam became more accessible to salmon due to reduced flows during peak spawning periods. Spring-run salmon remain in lower stretches of the river due to cooler, more optimum temperatures. Striped bass and shad were less common above Balls Ferry since water temperatures were cooler. Many native fish and introduced species (centrarchids and catfish) moved into warmer tributaries and were less abundant in the upper river. During drought periods, releases may be minimal, causing warmer water which could be detrimental to salmon.

77. Nordstrom, D. K. 1977. Hydrogeochemical and microbiological factors affecting the heavy metal chemistry of an acid mine drainage system. Doctoral Dissertation, Stanford University.

Abandoned copper mines in Shasta County, California, contain massive sulfide ores (dominantly fine-grained pyrite) and tailings that are weathered and oxidized to form strongly acid mine drainage (as low as a pH of 0.8). Effluents from the mines contain high concentrations of iron, copper, zinc, aluminum, cadmium and sulfate. High concentrations of iron, copper, zinc, cadmium and sulfate in the initial effluent are

governed by the oxidative breakdown of pyritic ore by groundwaters infiltrating faults and stopes. High concentrations of aluminum and many mineral constituents result from acid water dissolution of parent material.

Solute concentrations were found to increase with an initial rise in discharge due to the dissolution of soluble sulfate minerals that precipitate along stream banks and the rapid rise in the discharge of smaller polluted tributaries relative to the more slowly rising, unpolluted main stream. During low flow, solute concentrations are limited by the solubility of oxide, hydroxide and sulfate minerals.

Rapid rates of iron oxidation in the streams, which cause the precipitation of ferric iron minerals, are controlled by the growth of *Thiobacillus ferrooxidans*, an iron-oxidizing bacterium.

78. Nordstrom, D. K., and G. Stoner 1977. Acid mine drainage from Iron Mountain, Shasta County, California. The problems and an examination of treatment procedures. Univ. Virginia.

Acid water from massive sulfide ore bodies are issuing from several inactive copper mines in Shasta County at Iron Mountain. The ore consists of pyrite, chalcopyrite and sphalerite and is oxidizing to form acid sulfite solutions containing high concentrations of iron, copper, zinc, cadmium, and aluminum. The purpose of this study is to pinpoint specific sources of high acid effluent so that they can be treated.

At least 85 percent of all iron, zinc, and cadmium can be traced to the copper recovery plant effluent. Water from this plant is drawn from pools in the Richmond and Hornet Mines which produce some of the most acid metalliferous waters known to occur in nature. Although the recovery plant removes up to 98 percent of the copper entering the plant, high copper concentrations have been allowed to discharge from the plant (up to 157 mg/L). Less than 5 mg/L should be allowed to leave the plant. Additional treatment is recommended.

A second source of metal loading into Spring Creek is the weathering of several mine tailings on the east slopes of Iron Mountain which drain into Boulder Creek. The increase in concentrations of sulfates can be attributed to the dissolution of efflorescent sulfate crusts which form on and near pyrite grains and in the tailings. Even during dry periods acid seeps will issue from tailing piles. It is therefore urgent to treat the piles as soon as possible.

The third source of pollution is two seeps located in Slickrock Canyon below Iron Mountain. These seeps contribute most of the acids and heavy metals into Slickrock Creek.

Mine waters tend to have high concentrations of ferrous iron because contact with

sulfide ore keeps dissolved iron in a reduced state. After water leaves the ore, the ore becomes oxidized. Since this oxidation requires air or water, it is necessary to keep the sulfides out of contact with air or water to alleviate acid mine drainage. Treatments for prevention of oxidation include mine sealing, water diversion, chemical and biological inhibitors, or exclusion of air by covering with chemical sprays. Of these treatments, only water diversion is recommended for use in the Iron Mountain area.

Another approach used in reducing acid mine waters is to treat the acid effluent after it is formed. Treatments commonly used are limestone, lime, caustic soda or soda ash. Sludge disposal would be a problem with this approach, as well as cost of materials and unusually high ferrous iron concentrations in the Iron Mountain area.

Temporary measures such as diversion routes and small copper recovery plants should be immediately employed until a more permanent solution is reached. The authors recommend that efforts be made to extract valuable metals from the water so that they could be marketed. The process they would like to test would be a progressive electrochemical extraction of metals and acid followed by a progressive neutralization. If this process works, it could pay for itself and contribute toward the cost of water treatment.

79. Patton, A. V. 1978. Irrigation efficiency in the Colusa County Water District. Calif. State University, Chico. Master's Thesis.

The purpose of this paper was to determine whether or not the Colusa County Water District (CCWD) almond growers apply irrigation water efficiently. Efficient irrigation was defined as that which maximizes crop yield and provides for long-term maintenance of the land and standing crop.

Irrigation efficiency was estimated by comparing potential evapotranspiration with applied water. Evapotranspiration was determined by an adjusted pan evaporation method. In addition, a model was developed for weighing water inputs against outputs and for modulating soil moisture content. Using these models, it was determined that monthly evapotranspiration in the district exceeds water supply during much of the growing season, and that water supply does not meet crop needs. This supports the first hypothesis.

According to this paper, factors which impede grower efficiency include cultural and economic factors, but the most immediate restriction on increased irrigation rates is limited water supply. Experimental results of the University of California Agricultural Extension Service reveal a 38 percent increase in nut-meat yield with a seasonal irrigation of 50 inches instead of the average 24 inches per season in the CCWD. A comparison between the Chico Durham area and CCWD shows that Chico area growers apply 30-36 inches of irrigation per season for an average crop yield of 840

pounds of nut meats per acre, while CCWD growers have an average crop yield of 500 pounds per acre. These two lines of evidence suggest that increased water supply provided by the Tehama-Colusa Canal could improve crop yield in the CCWD.

80. Prokopovich, N. P. 1965. Siltation and pollution problems in Spring Creek, Shasta County, California. J. Am. Water Works Assn. 57(8)

Two major problems have been created in the Spring Creek basin: high erosion-sedimentation and highly acidic soils and water. These problems have created a biological desert in Spring Creek and have been related to many fish kills in the upper Sacramento River.

Geologic history, mining history, erosion and deforestation are discussed. In addition, a mostly unsuccessful 1948 attempt of reforestation is mentioned.

A copper precipitation plant was constructed and updated in 1958. In 1964 fifty tons of copper were collected from the plant.

The Spring Creek debris and pollution control dam has a maximum storage of 5,800 acre-feet. The author feels that with controlled releases of Trinity River and Spring Creek Control Dam water, the creek should be virtually harmless. (NOTE: Problems still exist.)

81. Prokopovich, N. P. 1981. Acidic surface deposits in California and Nevada. California Geology.

Acidity and alkalinity of soils and water are important environmental factors. Human activities change these factors, causing many hazards.

Spring Creek is one of the most acidic drainages in California. The creek is 14-1/2 miles long and a tributary to the Sacramento River. The Spring Creek drainage basin covers approximately 17 square miles. Creek flow ranges from 1 to 3 cfs in summer to more than 3,000 cfs during winter floods.

The drainage basin is underlain mostly by Paleozoic metasedimentary and metaigneous rock (such as the Bragdon Formation, Copley Greenstone and Balaklala Rhyolite) with Mesozoic granitic intrusions. This area is part of the Shasta Copper-Zinc District. Most of the topsoils in the area have a pH of 5-7.

Natural geologic conditions of the past suggest that sulfide minerals in the Shasta Copper-Zinc District were subjected to slow surface oxidation. Leaching occurred and formed a spongy, iron-rich capping known as gossan. It was discovered that unoxidized copper-bearing ore was underlying the gossan. In 1895, underground mining started. A railway connected the mine to a smelter located near the mouth of

Spring Creek. In 1904, the smelter processed over 1,000 tons of ore per day. In 1907, the pollution impact of smelter fumes led to cessation of smelting. Mining of copper and zinc was discontinued in 1930, except for a brief period of resumption at the end of World War II. Highly acidic, metal-laden runoff continued to pollute Spring Creek by oxidation of sulfide minerals in open pit mines.

Studies in 1959-60 indicated that the pH of waste soil from the mines was as low as 1.4-3.5.

During flood stages, copper and zinc reach the Sacramento River and cause fish kills. Spring Creek Diversion Dam was constructed to minimize runoff pollution into the Sacramento River.

Generally the pH of Spring Creek near the Sacramento River ranges from 2.8 to 3.6. Drilling equipment used on the debris dam was highly corroded due to the acidity of the water and soil.

82. Sanford, G. R.; D. E. Bayer; and A. W. Knight 1974. An evaluation of environmental factors affecting the distribution of two aquatic mosses in the Sacramento River near Anderson, California. Dept. Water Science and Engineering. U. C. Davis.

This report dealt with the aquatic moss *Hygrohypnum ochraceum* and the effects of Simpson Lee Paper Mill effluent on its growth. Additionally, some data are presented on growths of the aquatic moss *Scleropodium obtusifolium*. Biotic factors (presence or absence, distribution, abundance, population dynamics and habitat affinities) were observed in the field, and abiotic data (specific conductance, 22 different ions, pH, temperature, dissolved oxygen, free carbon dioxide, and current velocity) were collected.

Excellent growths of *H. ochraceum* occurred both above and below the mill outfall. It ranged from Keswick Dam to Iron Canyon below Bend Bridge (no observations were conducted below Red Bluff) occurring mainly in riffle areas. No evidence was found to implicate mill effluent as affecting growth.

Abiotic factors showed very little change from above to below the outfall. Carbon dioxide was consistently greater below the outfall, but this occurred even when no effluent was entering the river.

Laboratory experiments suggested that effluent did not stimulate growth.

Three factors appeared of special significance to growth of *H. ochraceum*: temperature, current velocity and carbon dioxide (CO<sub>2</sub>) concentration. Current velocity

appeared to be important in field studies, while CO<sub>2</sub> was critical in the laboratory. A possible explanation may lie in the moss requiring fast-moving water because such water would steepen the CO<sub>2</sub> diffusion gradient from the water to stems and leaves. Data on pH suggested there was a greater CO<sub>2</sub> deficit in areas without the moss.

83. Shimizu, Steven J., and Charles R. Goldman 1979. Population dynamics and production estimates of the California crayfish, *Pacifastacus leniusculus* (DANA), in the Sacramento River. Bull. Ecol. Soc. Amer. V: 60(9).

The population dynamics of the crayfish *Pacifastacus leniusculus* were studied in an effort to not only compare populations from different aquatic environments, but also to provide management guidelines for the Sacramento River commercial crayfish fishery. The natural history of *P. leniusculus* was investigated in a one-fourth mile section of the Sacramento River from May 1977 to December 1978. Data on fecundity, recruitment, mortality, growth, and behavior were obtained and an estimate of annual crayfish production was calculated.

84. Smarkel, K. L. 1979. Mammoth Mine, Shasta County. Water Quality Control Board Memorandum to J. C. Pedri.

A sampling inspection of Mammoth Mine was made on March 12, 1979. Data in September 1978 on Little Backbone Creek indicated that the tributary from the main Mammoth pile contributed most of the copper, zinc, and cadmium during dry periods. Concentrations were reduced 30-40 percent from the adit to the base of the pile, probably due to dilution by springs.

The March 1979 samples showed that little, if any, heavy metals were contributed by the waste pile. Copper concentrations at the Friday-Lowden discharge were higher than previously found and sometimes exceeded 10 mg/L. The Friday-Lowden and main Mammoth portals were identified as possible candidates for mine sealing.

85. Tanji, K. K. 1981. California irrigation return flow case studies. J. Irrig. Drainage Div., Proc. Am. Soc. Civ. Eng. 107 (IR2)

The impacts of irrigation return flows on the quantity and quality of the Sacramento and San Joaquin Rivers were appraised. Quantity of return waters is influenced by availability and cost of supply water, irrigation application methods, extent of reuse on site and within the basin, special cultural practices, and constraints on reuse caused by pollutants. Quality of return flows is influenced by quality of supply water, presence of salts and chemicals native to the soils, leaching, use of manure and other agricultural chemicals, erodibility, discharges into irrigation drains, and the relative proportion of surface and subsurface flows. Analyses indicated that the quantity and quality of return flows are highly variable. Priority issues for agricultural planning

pertain to soil erodibility and sediment production, and pesticide residues in return flows.

86. Turek, S. M. 1981. The ecological impact of filter feeding by *Pectinatella magnifica* (Phylum Ectoprocta). Calif. State University, Chico, Master's Thesis.

*Pectinatella magnifica* occurs in large numbers in backwaters and sloughs of the Sacramento River. They are active during the spring and summer when water temperatures exceed 16°C.

A field analysis was performed to determine filtering rates for different-sized colonies of *P. magnifica*. A rough population estimate was made for Wilson's Landing Slough near Chico.

A significant positive exponential relationship was found between filtering rate (l/hr) and colony size (cm<sup>2</sup>). An average-sized colony (900 cm<sup>2</sup> or 17 cm in diameter) filtered about 150 liters per hour. The estimated population of 10,500 colonies in Wilson's Landing may filter nearly 1.5 million liters of water per hour and remove as much as 5.2 Kg of organic matter per hour. These values work out to approximately one-third of the daily primary production of the slough being removed daily. Therefore, *P. magnifica* may represent an important planktonic regulator where it occurs in large numbers.

87. University of California, Davis 1980. Non-point sediment production in the Colusa Basin drainage area. Second-year annual progress report on EPA Grant No. R805462, Oct. 1978-Sept. 1979. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4018.

The Colusa Basin Drain (CBD) conveys flood runoff and irrigation return flows from about one million acres of watershed and agricultural land on the west side of the Sacramento River. It is one of the two largest sources of agricultural return flows discharged into the river. Data indicate that CBD contains a significant amount of suspended solids that raises the turbidity of the Sacramento River, especially during storm runoff.

This project attempts to identify non-point sources of suspended matter in the CBD area, to understand factors contributing to or affecting suspended solids loading and to develop recommendations for best management practices.

The basin was divided into 24 subbasins in which sediment production was estimated. Comparisons were made between estimated and measured sediment loadings at selected sites and in subbasins.

Weekly monitoring of flows and suspended matter was conducted at eleven stations.

Monitoring on a monthly or lesser time interval was conducted on an additional fifteen stations.

The data showed that highest concentrations of suspended solids (SS) coincide with peak storm flows. Maximum and average SS concentrations were greater in nonirrigation season.

Three general areas of concern were identified: bare level basin soils, moderate to steep cultivated soils, and steep noncultivated foothill land. Recommended management practices include: careful management of soil cover and grazing animals on steep, non-cultivated land; prudent farming practices utilizing grassed waterways and contour strips on cultivated steeper lands; and farm water conservation and water recycling on nearly level basin soils.

When current velocity is high in the CBD, bed materials tend to be coarser. When velocity drops, small silt and clay particles accumulate.

The organic carbon content of the suspended matter was comparatively small (1.5 to 4 percent), indicating that sediments are essentially mineral in character.

River water contained one-fifth the suspended solids concentration and had twice the organic content.

The sediment makeup, determined by x-ray diffraction, is discussed.

From a water quality standpoint, there is significant erosion and sediment production in the CBD. Approximately 269,000 tons of soil or 177 tons/mile<sup>2</sup> could be eroding yearly.

88. University of California, Davis 1980. Nonpoint sediment production in the Colusa Basin drainage area. Annual report to EPA on EPA Grant No. R805462, 1979-1980. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4019.

This project was a continuation of the 1977-79 project. Monthly or more often monitoring of fifteen stations continued. Three pesticides were chosen for monitoring during this study.

Once again highest concentrations of suspended solids coincided with peak storm flows and were greatest during nonirrigation season.

Organic content of sediments was low. Sediments were largely mineral and derived from soils of the Colusa Basin.

Sodium, sulfate, and bicarbonate were the dominant soluble ions in the Colusa Basin Drain (CBD). While sodium was the dominant soluble cation, it was lowest among the exchangeable cations adsorbed to suspended matter. Calcium and magnesium dominated among exchangeable cations.

In February, April, and September, pesticide concentrations (MCPA, molinate and parathion) were below detection limits in the CBD. In May 1980, there was an increase in molinate concentration.

An analysis of CBD suspended sediment showed an increase with downstream progression in algal biomass and concentrations of total dissolved solids, suspended solids, and organic matter. Algal biomass was exponentially correlated with orthophosphate in the drain ( $r = 0.91$ ).

89. University of California, Davis 1981. Nonpoint sediment production in the Colusa Basin drainage area. Annual report to EPA on EPA Grant No. R807169, 1980-1981. Dept. Land, Air, and Water Resources. Water Science and Engineering Paper No. 4022.

This report completes the final year and involved factors and causes contributing to the turbidity problem in the Colusa Basin Drain (CBD). The CBD was monitored for flow, turbidity, total dissolved solids (TDS), conductivity (LC), and suspended solids (SS).

The discharge of water and sediment from the CBD in 1981 was less than previous years because the amount of precipitation was less.

Linear relationships were established between SS and current velocity, flow rate, and turbidity.

Of the water delivered to irrigation croplands in 1981, three-fourths was used in rice production.

Once again, concentrations of SS were higher in the nonirrigation season.

The plume originating at the CBD outfall at Knights Landing was studied to determine the effects of CBD on the Sacramento River. Nine stations were monitored for turbidity, EC, color, and chlorophyll-a.

Turbidity decreased as CBD water mixed with the river. Suspended particle concentrations decreased exponentially with plume width. Water from the CBD increased the EC of the river substantially. Color also increased with the maximum change occurring in late September, corresponding to an increase in discharge from rice fields with a high concentration of suspended organic particles.

The pesticide molinate showed a steady and rapid increase in the CBD from April to June 1981 and rapidly decreased in June. Methyl parathion was also detected.

A dynamic mathematical and computer model was developed for simulation of suspended matter transport in the CBD. A user's manual was developed and completed.

90. U. S. Army Corps of Engineers 1980. Sacramento River aerial atlas.

This is an atlas using 41 aerial photographs of the Sacramento River from Suisun Bay to Shasta Dam. River miles are designated using Collinsville as a starting point. In addition, levees, tributaries, communities, canals, bypass structures, and gaging stations are shown.

91. U. S. Bureau of Reclamation, Mid-Pacific Region 1982.. Central Valley fish and wildlife management study, Issue No. 1.

This program was developed cooperatively by representatives of various State and Federal agencies. Thirty present and future fish and wildlife problems have been identified and an order of priority determined. Three major categories include fish, wildlife, and reservoir and miscellaneous.

Several anadromous fish studies are identified. River flows and spawning habitat of the upper Sacramento River are being assessed, including requirements for instream flow and spawning gravel, methods for meeting needs and benefits to salmon. Predation studies are suggested. Studies on problems with the Red Bluff Diversion Dam, Tehama-Colusa Fish Facility and the Anderson-Cottonwood irrigation District Dam at Redding are warranted, along with evaluation of fish production facilities and their operations.

Changing Central Valley waterfowl habitat is addressed. A historical overview is presented. A study was under way to investigate and identify sources of firm water supplies for refuges and management areas. The second phase of determining the need for new waterfowl areas and ways to provide it was not under way.

Toxic mine drainage from Spring Creek was controlled with Spring Creek Reservoir and dilution releases from Shasta Lake. Sometimes runoff exceeds the capacity of the reservoir (Spring Creek) and dilution releases from Shasta Dam cannot be made because of potential flooding. The Bureau is evaluating various long-term water management solutions, including enlargement of Spring Creek Dam and diversion of nontoxic flows from Spring Creek into the river. The Water Quality Control Board is concentrating its efforts on controlling the pollution at the source.

Drought conditions can cause elevated temperatures in the Sacramento River which

adversely impact salmon spawning. Consequently, an evaluation was being made of a multilevel intake structure at Shasta Dam using mathematical models of Shasta Lake and the upper Sacramento River.

Finally, an investigation was under way of alternative plans for solving problems of conflicting land uses along the river.

92. U. S. Bureau of Reclamation, Mid-Pacific Region 1982. Minutes of the joint core group and advisory group meeting, Central Valley fish and wildlife management study.

This meeting was an update on activities by the three plan formulation teams (Anadromous Fish, Wildlife and Reservoirs and Miscellaneous). Each team leader presented tentative findings and conclusions for several investigations that were discussed in the Central Valley Fish and Wildlife Management Study, Issue 1, earlier in the year.

93. U. S. Environmental Protection Agency 1974. National water quality inventory. Report to Congress, Vol. I.

The Sacramento River was one of many national rivers identified as a major problem drainage of low-level quality. Goals were presented for 1977-1983 to protect and balance populations of shellfish, fish and wildlife. Recreation was also included in these goals. The Sacramento River is one of California's most difficult non-point source problems stemming mainly from agriculture, specifically related to high nutrient concentrations.

94. U. S. Fish and Wildlife Service 1959. Effects of mine-waste on anadromous and resident fish in the upper Sacramento River.

Keswick Reservoir and the Sacramento River are polluted by heavy metals and acid pollutants from mines, waste dumps, and natural mineral deposits. Food supply as well as fish are adversely affected by the pollutants. This report reviewed available files, reports, and published material to correlate fish kills, flow regimes and pollution.

Spring Creek contributed 90 percent of the pollutants, composed of sulfurous and sulfuric acids, iron sulfates, copper and zinc sulfates, and other dissolved toxic compounds. Copper and zinc are strongly synergistic in their toxic effects.

A dilution ratio of Spring Creek water of 1:54 downstream from Shasta and 1:50 downstream from Keswick Reservoir contributed to an April 1956 fish kill. Dilution ratios of 1:4 to 1:87 downstream from Keswick and 6:1 to 1:20 downstream from Shasta resulted in four adult kills between November 1955 and February 1957. A serious fish kill occurred in January 1957 during heavy runoff, and a dilution ratio of

1:20.

September-December fish kills are associated with the first heavy rain which flush summer accumulations of toxic sediments into the reservoir and river. Heavy rains are required to cause a kill between January and April.

Maximum releases from Shasta Reservoir, in combination with heavy runoff from Spring Creek, flush accumulations of toxic water out of Keswick and may cause fish kills below Keswick Dam.

Plans for abating mine-waste pollution are presented from Leeds, Hill and Jewett, Consulting Engineers (1957).

95. U. S. Geological Survey. Water resources data for California, water years 1961-1981. Volume 4. Northern Central Valley Basins and the Great Basin from Honey Lake Basin to Oregon state line. Series.

These reports contain tables of data including records of stage, discharge, and water quality of streams; stage, contents, and water quality of lakes and reservoirs; records of water levels in selected observation wells; and selected chemical analyses of ground water.

Hydrologic conditions are discussed and collection stations are listed. Some water quality parameters include specific conductance, pH, dissolved oxygen, water temperature, and sediment discharge.

These reports are valuable as references but very little discussion is included.

96. U. S. Geological Survey 1969. Data on dye dispersion in a reach of the Sacramento River near Red Bluff, California.

In late October 1969, data were collected on dye dispersion in the Sacramento River near Red bluff. The dye was injected at three points on three days (two points 60 feet above the diversion dam and one at the sewage outfall for Red Bluff 1.1 miles above the dam). A fluorescent dye (rhodamine WT) was used with a flow-through fluorometer for detection. The river was discharging 8,480, 8,460 and 8,440 cfs for the three days of experimentation. An average velocity of 0.67 feet per second was determined for a 5,800-foot reach from the sewage outfall to the dam.

97. U. S. Geological Survey 1972. Sediment transport in the western tributaries of the Sacramento River, California. Water Supply Paper 1798-J.

Sediment transport studies were made on the western tributaries of the Sacramento River from Clear Creek to Putah Creek. Impoundments in the area have a storage

capacity of  $2.5 \times 10^6$  acre-feet, and proposed impoundments would add  $3\text{--}7.5 \times 10^6$  acre-feet. About 960,000 acre-feet is imported yearly from the Trinity River. An additional future import of up to 950,000 acre-feet per year was planned from the Eel River. Most of the imported water is conveyed to the water-deficient south.

The quantity of sediment carried and deposited by streams may affect the quality of water and the operational regimen of reservoirs. Total average annual yield of suspended sediment from the study area was about 4.7 million tons. Approximately 30 percent is retained by entrapment in lakes and reservoirs. The remaining 70 percent is transported from the regions, most of it during relatively short periods of high streamflow.

98. U. S. Geological Survey 1974. Water quality data of the Sacramento River, California. May 1972-April 1973.

Measurements of suspended sediment, major dissolved chemical constituents, selected trace elements and plant nutrients, phytoplankton, periphyton, and benthic organisms were made at five sampling sites along a 175-mile (282-kilometer) reach of the Sacramento River between Red Bluff and Knights Landing. The study period began in May 1972 and continued on a near monthly basis through April 1973.

Mean suspended sediment concentrations ranged from a low of 3 mg/L at two upstream sampling sites in July and September to a high of 566 mg/L at one downstream sampling site in January. The dissolved-solids concentration ranged from a low of 75 mg/L at one upstream site in September to a high of 135 mg/L at the lowermost site in August. Phytoplankton concentrations increased in a downstream direction to a high of 980 cells per milliliter at one downstream site in September. The diatoms (class Bacillariophyceae) were the dominant group of algae present, both in numbers and diversity, at all sampling sites throughout the study period. The range of organic weight of periphyton (mean net community productivity) was 0.01 to 0.56 grams/m<sup>2</sup>/day throughout the five sampling sites. High concentrations of sediment were found in samples collected at the two lowermost downstream sites. The diversity of benthic organisms decreased in a downstream direction. The diptera, especially members of the family Chironomidae, were the most common organisms at all sites throughout the study period.

99. U. S. Geological Survey 1975. Letter to Dennis Wilson (CDFG), Region 1, from Kirk Nordstrom.

This letter includes a list of fish kills from 1940 through 1975 in Shasta Lake or near Redding, California. The table includes: date, location, fish species, number reported dead, and reference (Table B-1).

(INSERT SEPARATE FILE FOR TABLE B-1 HERE.)

Table B-1. Table of fish kills in Shasta Lake or near Redding

100. U. S. Geological Survey 1976. Variation in concentration of selected water quality constituents in the Sacramento River at Bend Bridge, California. Water Resources Investigation 76-14.

Two diurnal studies for various water quality parameters were conducted at Bend Bridge September 4 through 7, 1973. Parameters measured included temperature, discharge, dissolved oxygen, pH, specific conductance, calcium, magnesium, sodium, bicarbonate, sulfate, chloride, nitrate, ammonia plus organic nitrogen, total phosphorus, organic carbon, and phytoplankton concentration.

Blue-green algae were found in the highest concentration followed by diatoms and then green algae. A statistical analysis was performed to determine if there was a difference between water quality parameters at various depths and distances across the river. No statistical differences were found.

101. U. S. Geological Survey 1977. Heavy metal discharges into Shasta Lake and Keswick Reservoirs on the Upper Sacramento River, California: A reconnaissance during low flow. Water Resources Investigation 76-49.

This study was made to determine relative contributions of heavy metals to Shasta Lake and Keswick Reservoir during low flows. The report summarizes pertinent information on geology, hydrology, mining history and fish kills related to heavy metals in the area. Water was collected from 17 streams during November 5 through 8, 1974. Samples were filtered and acidified at the time of collection. Analyses included suspended sediments, temperature, pH, conductivity, discharge, cadmium (Cd), copper (Cu), iron (Fe), mercury (Hg), manganese (Mn), zinc (Zn), and lead (Pb).

West Squaw Creek, Little Backbone Creek, Flat Creek, Spring Creek and the east fork of Horse Creek were found to contribute acid mine wastes to the reservoirs. Water characteristics for these streams included low pH (5.0), high heavy metal concentrations (except Pb and Hg) and high conductivity.

The acidic waters and heavy metals were released by oxidation of massive fine-grained sulfide ores from mining localities. Flat Creek contamination arose from effluent of a ponded flotation tailing pile. Low pH prevents adsorption or precipitation of the heavy metals. Therefore, concentrations remained high until mixing with the lake water. Localized fish kills occur where the mixing takes place.

Heavy metal loads were calculated for the various tributaries. Spring Creek, West Squaw Creek, Little Backbone Creek and the Pit River were the major sources of heavy metal loading. The Pit River had low concentrations but high flows which made

it a major source. Spring Creek contributed 50 percent of the loading for every metal but Mn and Pb. Sixty-seven percent of the manganese loading was divided evenly between the Pit River and Spring Creek.

Further research is suggested including the synergistic toxic effects of copper, zinc and cadmium, the toxicity of arsenic, the effects of other variables on toxicity (complexation, sorption, ionic strength, hardness, and solubility), the chronic toxicity from metal buildup in the sediments, and the potential for bioconcentration of metals.

An excellent overview of research conducted in the area from 1939 to 1974 is presented as an appendix.

102. U. S. Geological Survey 1977. Distribution and abundance of benthic organisms in the Sacramento River, California. Water Resources Investigation 77-69.

This report compares benthic macroinvertebrate communities collected in 1960-61 (DWR) and 1972-73 (USGS) from five stations between Bend Bridge (near Red Bluff) and Knights Landing. The five sites were: at the Bend Bridge, below the Red Bluff Diversion Dam, at Colusa, above the Colusa Trough at Knights Landing, and at Knights Landing. The upper two stations were riffles, the middle station was a long pool, and the lower two stations were dredged and leveed channels. Samples by USGS were collected with Peterson or Ponar dredges. Samples by DWR were collected with a Surber sampler at the upper two stations and a Peterson dredge at the others.

Caddisflies of the family Brachycentridae were collected in 1972-73 from the upper two stations but were not in 1960-61. Corbiculid clams found at the two lower stations in 1960-61 were again found in 1972-73, but their range had extended to the Colusa station.

Benthic organism composition did not vary greatly between the two studies. Differences were explained by differences in sampling location, collection equipment and sample handling.

In general, there was an increase in the mean density of organisms from May to September and a decrease from September to April for both studies. Species richness, community density and community diversity (as measured by the Shannon-Weaver Diversity Index) were higher in the upper stations than the lower stations.

103. U. S. Geological Survey 1978. An evaluation of problems arising from acid mine drainage in the vicinity of Shasta Lake, Shasta County, California. Water Resources Investigation 78-32.

The purpose of this study was to determine the extent and magnitude of acid and

metal pollution and to identify point sources; to conduct more comprehensive studies on a few selected areas; to suggest possible abatement procedures; and to design a water-quality monitoring program to determine the effectiveness of treatment and abatement procedures.

A brief history, climatic conditions, and geology of the study area is presented.

Field studies were conducted on 17 tributaries to Shasta and Keswick Reservoirs in November 1974 (low flow) and April 1975 (high flow).

Six creeks (Flat, Little Backbone, Spring, West Squaw, Horse and Town) carried dissolved metal concentrations that accounted for most of the metals discharged into the upper Sacramento River. Spring Creek was the largest contributor. Some dissolved metal loads were large (i.e. Pit River) due to the large volume of water rather than high concentrations of metals.

The West Squaw Creek and Little Backbone Creek Basins were chosen for more intensive study. This portion of the study included an evaluation of acid generation and metal mobilization, additional sampling to determine specific sources, and an evaluation of the effects of specific sources of effluent on the chemical and biological water quality. Each drainage basin (West Squaw Creek and Little Backbone) and its specific pollution sources (mines and tailings) are discussed.

Possible mechanisms for acid generation (oxidation of pyrite and the subsequent oxidation of ferrous iron) and metal mobilization are discussed.

Three types of mine tailings were identified (processed ore, pyritic mine waste, and country rock with very little pyritic material). Examples of each and their effects on water quality are presented.

Benthic macroinvertebrates were collected during the autumn of 1975 in West Squaw Creek (five sites) and Little Backbone Creek (seven sites). West Squaw Creek communities were of poor biological quality with low species richness, densities and diversity indices. The same trend was observed in Little Backbone Creek with a richness of 2 to 6 species and diversity indices below 1.0. The density of organisms was much higher, however, than West Squaw Creek. Two stations above the influence of acid mine drainage showed healthy species richness, density and diversity for the macroinvertebrate community.

Laboratory experiments were conducted on the relationship of water contact time with dump materials and acid generation, metal release, and acid generation capacity. Major findings included an initial flux of highly acidic water when water comes in contact with mine wastes, followed by decreases in acid generation. Acid generation in deoxygenated water was found to be almost identical to oxygenated water. These

findings indicated the presence of ferric iron (which can form acid under anaerobic conditions), and the potential for the production of major quantities of acid and dissolved metals in the first runoff from mine tailings following dry periods. Control of acid mine effluent is discussed. Treatment methods were lumped into three categories: (1) sealing, (2) treatment (neutralization), and (3) infiltration control. Advantages and disadvantages of each method are presented.

Abatement procedures are suggested for different mines and problem areas. A demonstration program is outlined for the Weil Portal of the Balaklala Mine, along with a water quality program to determine the effects of the abatement procedures.

104. U. S. Geological Survey 1978. Drought in California--water resources data for 1977. Open-File Report 78-613.

The two-year dry period (1976-77) was the most severe drought in Northern California's history, and the quantity and quality of all water supply sources in the State were affected. This report contains special water resources data collected by the Geological Survey during 1977. These data include: streamflow at eleven selected stations, comparing 1977 mean monthly and yearly flow to the period-of-record medians; base-flow measurements at 189 sites; water quality at 131 sites; ground water levels in wells and river stages along a 158-mile reach of the Sacramento River; and graphs showing the effect of tidal action on suspended sediment concentration of the Sacramento River at Sacramento.

105. U. S. Geological Survey 1978. Observations of water quality in the mixed reach below the confluence of the Sacramento and Feather Rivers, California. August and November 1975. Water Resources Investigation 77-91.

Water quality measurements were made in diurnal studies during August 13-14 and November 4-5, 1975. Three stations were established (one in the Sacramento River above the Feather River, one in the Feather River and one below the confluence of the two rivers.

Biotic components measured included phytoplankton and benthic drift organisms. Abiotic parameters studied included temperature, specific conductance, dissolved oxygen (DO), pH, silica, phosphorus and organic carbon.

Most water quality parameters were significantly higher in the Sacramento River above the confluence than in the Feather River. However, the temperature in August and the DO in November were significantly higher in the Feather River.

Most water quality values in the mixed reach showed no significant difference between theoretical and measured values for mixing. Specific conductance and silica, however, were higher than the theoretical values in both study periods.

Possible explanations included upwelling near the confluence, concentration by evaporation or plant and animal activities.

Temperature and DO showed diurnal cycling with peaks in the afternoon and lows at night. The DO cycle, however, was not evident in November in the Feather River or below the confluence.

The phytoplankton showed lower concentrations in November. Three major phyla in their order of abundance were Chrysophyta, Chlorophyta and Cyanophyta.

Faunal drift was composed of both terrestrial and aquatic insects; mainly aphids, black fly larvae, and midge fly larvae were observed. Peaks in drift occurred in evenings and early morning.

106. U. S. Geological Survey 1979. Data compilation of periphyton colonized on artificial substrates placed in the Sacramento and Feather Rivers, California, 1975. Open-File Report 79-696.

This report presents methods of analysis and data for periphyton samples from the Sacramento and Feather Rivers. The samples were taken from August 5 to September 29, 1975. Three stations were sampled: one in the Sacramento River above the confluence with the Feather River, one in the Feather River and one below the confluence of the two rivers.

Periphyton was collected from polyethylene strips for determination of species composition and biomass. Other parameters measured at each site were water temperature, specific conductance, pH and dissolved oxygen. In addition, water samples were analyzed for dissolved and suspended organic carbon, dissolved and organic phosphorus, silica, suspended sediment, and phytoplankton.

The rest of the report is presented as three tables showing physical chemical data, periphyton and phytoplankton species composition, and concentrations and periphyton biomass. No discussion is presented.

107. Wilson, D.; B. Finlayson; and N. Morgan 1981. Copper, zinc and cadmium concentrations of resident trout related to acid mine wastes. Cal. Fish and Game 67(3).

Resident trout from four locations in the upper Sacramento River Basin, California, were surveyed for copper, zinc and cadmium concentrations in their flesh (muscle) and liver tissues to determine the impact of acid mine wastes on tissue metal contamination. Three of the sampling locations receive acid mine drainage containing copper, zinc and cadmium; the fourth location was believed to be devoid of these influences. Metal analyses of water samples collected near the sampling

stations confirmed the presence or absence of acid mine wastes.

No relationship was obvious between the flesh metal concentrations and the size or age of trout, nor between the flesh metal concentrations and the concentrations of copper, zinc or cadmium in the water. Mean flesh concentrations (fresh weight) from the four locations varied between 0.20 and 0.31 ppm Cu. 2.50 and 4.61 ppm Zn, and 0.020 and 0.021 ppm Cd. These levels are similar to the published background levels in the continental United States. However, liver metal concentrations increased with increased copper, zinc and cadmium concentrations in the water, and copper and cadmium liver concentrations increased with fish length, weight and age at several locations. Mean liver concentrations (fresh weight) from the locations of the lowest and the highest water metal concentrations were 76 and 287 ppm Cu. 35 and 57 ppm Zn and 0.3 and 4.0 ppm Cd, respectively, suggesting that liver metal concentrations rather than flesh metal concentrations reflect available metal concentrations present in the environment. Additionally, the higher copper and cadmium concentrations in liver were above published background levels, which indicates that the fish populations at these locations are receiving detrimental exposures to these metals.

108. Zanella, E. F. 1982. Shifts in caddisfly composition in Sacramento River invertebrate communities in the presence of heavy metal contamination. Bull. Environm. Contam. Toxicol. 29.

Benthic macroinvertebrates were monitored over an 18-year period in a 30-mile stretch of the Sacramento River between Anderson and Red Bluff, California.

Four replicate samples were collected with a Surber sampler at each station on each date. The samples were treated separately and preserved in 10 percent formalin. Invertebrates, preserved in formalin for 1/2 and 4-1/2 years were analyzed for cadmium, copper and zinc.

During the 18-year study, dipterans were represented by more taxa, but trichopterans were numerically dominant. The benthic community is described as moderately diverse and moderately productive.

The relative community composition remained consistent from station to station. There was some fluctuation in total species diversity, which was a function of habitat differences between riffles.

An inspection of the distribution of individual species over the long term spanned by this study showed a marked change in the abundance of two dominant caddisflies (*Brachycentrus americanus* and *Hydropsyche* sp.). *Brachycentrus* dominated during the 1960s and early 1970s. By 1978, a clear reversal had occurred with *Hydropsyche* dominating.

During the 18-year study, the benthic invertebrate standing crop steadily increased while species richness and composition remained relatively constant. The *Hydropsyche* and *Brachycentrus* shift was the only major change in community structure. It is suggested that this shift is due to a selective susceptibility to the toxicity of heavy metals (zinc, copper and cadmium).

Storet and Department of Fish and Game heavy metal data are presented to show an increase in metal concentrations (Sacramento River at Redding) in 1979 from 1976.

The 1980 mixed invertebrate tissue heavy metal data indicated a decreasing downstream progression of cadmium and zinc. Cadmium and zinc levels were higher in caddisfly flesh in 1980 than 1976. Copper, however, was lower.

*Hydropsyche*, for the most part, had higher metal concentrations than *Brachycentrus*.

#### APPENDIX C, MISCELLANEOUS INFORMATION AND DATA ON FILE WITH THE CALIFORNIA DEPARTMENT OF WATER RESOURCES, NORTHERN DISTRICT

109. Arbuckle Problem Area. Water Quality and Biology Section. Data binder.

Most of the material in this binder is devoted to the problems of boron in ground water near Arbuckle in the Sacramento Valley. Some surface water information is presented for several streams and State Water Quality Monitoring Program station 87 in the area. A list of stations, descriptions, locations and source is found under the Surface Water heading. Most of the information is from 1952 through 1961.

Colusa trough water was classified as sodium-magnesium bicarbonate and occasionally Class 2 for irrigation (due to high conductivity). Hardness ranged from slightly to very hard. During the irrigation season the water reflects high mineral conditions since it is used and reused for agricultural purposes.

110. Colusa Basin Drain Maps and Graphs, September 1975-April 1976. Water Quality and Biology Section. Data binder.

A graphical presentation of data collected from 16 stations within the Colusa Basin Drain is shown for electrical conductivity, turbidity, sulfate and chloride (September 1975 to April 1976). These data are also presented on schematic line maps of the basin for each date of collection.

Both graphical and tabular records of discharge for the Colusa Basin Drain at College City and Highway 20 are found loose in the binder (October 1975 to January 1977). Highest flows were observed in May, August, and September. Highest conductivities

corresponded to lower flows from December 1975 through February 1976.

Also included is a computer readout for monthly pesticide use in Colusa County from January 1977. The readout is from the State Department of Food and Agriculture and includes chemical used, crop, pounds used, and acres treated for the year to date.

111. Department of Water Resources. Water temperature data. Data binder.

The Department has a semicomplete file of water temperature data for the Upper Sacramento Valley. The binder is in two parts. Section 1 contains data from 1939 to 1948 on the Sacramento River, Trinity River, Anderson-Cottonwood Irrigation District Canal and Battle Creek. Section 2 includes data on the Sacramento River, Battle Creek, Mill Creek, Deer Creek, Mokelumne River, San Joaquin River, Old River and Contra Costa Canal from 1949 to 1951. The data are presented as daily maximums and minimums in tabular form. Monthly maximum/minimum averages are also presented.

The index to tables for Sections 1 and 2 is included here to show the stations and dates for the data (Table C-1 and Table C-2).

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6 Sacramento River at Balls Ferry, 1946 .....	11
7 Sacramento River at Balls Ferry, 1947 .....	12
8 Sacramento River at Balls Ferry, 1948 .....	13
9 Sacramento River at Squaw Hill, 1945 and 1946 .....	14
10 Sacramento River at Squaw Hill, 1947 .....	15
11 Sacramento River at Squaw Hill, 1948 .....	16
12 Sacramento River at Ords Ferry, 1948 .....	17
13 Sacramento River at Knights Landing, 1947 .....	18
14 Sacramento River at Knights Landing, 1948 .....	19
15 Sacramento River at Sacramento, 1939 .....	20
16 Sacramento River at Sacramento, 1940 .....	21
17 Sacramento River at Sacramento, 1941 .....	22
18 Sacramento River at Sacramento, 1942 .....	23
19 Sacramento River at Sacramento, 1943 .....	24
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21	Sacramento River at Sacramento, 1945 .....	26
22	Sacramento River at Sacramento, 1946 .....	27
23	Sacramento River at Sacramento, 1947 .....	28
24	Sacramento River at Sacramento, 1948 .....	29
25	Sacramento River at Walnut Grove, 1947 .....	30
26	Sacramento River at Walnut Grove, 1948 .....	31
27	Sacramento River at Rio Vista, 1948 .....	32
28	Trinity River at Lewiston, 1942 and 1943 .....	33
29	Trinity River at Lewiston, 1944 .....	34
30	Trinity River at Lewiston, 1945 .....	35
31	Trinity River at Lewiston, 1946 .....	36
32	Trinity River at Junction City, 1945 and 1946 .....	37
33	Anderson-Cottonwood Irrigation District Canal near Anderson, 1948 ..	38
34	Anderson-Cottonwood Irrigation District Canal west of Cottonwood, 1947 .....	39
35	Anderson-Cottonwood Irrigation District Canal west of Cottonwood, 1948 .....	40
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37	Battle Creek at Old Battle Creek Hatchery, 1940 .....	42
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53	Feather River at Yuba City, 1946 .....	58
54	Feather River at Yuba City, 1947 .....	59
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11	Sacramento River at Squaw Hill, 1949 .....	16
12	Sacramento River at Squaw Hill, 1950 .....	17
13	Sacramento River at Squaw Hill, 1951 .....	18
14	Sacramento River at Ords Ferry, 1949 .....	19
15	Sacramento River at Ords Ferry, 1950 .....	20
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17	Sacramento River at Meridian, 1949 .....	22
18	Sacramento River at Meridian, 1950 .....	23
19	Sacramento River at Meridian, 1951 .....	24
20	Sacramento River at Knights Landing, 1949 .....	25
21	Sacramento River at Sacramento (Water Works), 1949 .....	26
22	Sacramento River at Sacramento (Lowry's Landing), 1949 .....	27
23	Sacramento River at Sacramento (Water Works), 1950 .....	28
24	Sacramento River at Sacramento (Hay's Landing), 1950 .....	29
25	Sacramento River at Sacramento (Water Works), 1951 .....	30
26	Sacramento River at Sacramento (Hay's Landing), 1951 .....	31
27	Sacramento River at Walnut Grove, 1949 .....	32
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32	Mill Creek near Los Molinos, 1950 .....	37
33	Mill Creek near Los Molinos, 1951 .....	38
34	Deer Creek near Vina, 1949 .....	39
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36	Deer Creek near Vina, 1951 .....	41
37	Mokelumne River, South Fork, 1949 .....	42
38	San Joaquin River at Mossdale, 1949 .....	43
39	San Joaquin River west of Stockton, 1949 .....	44
40	Old River at Clifton Court, 1949 .....	45
41	Contra Costa Canal at Oakley, 1949 .....	46
42	Contra Costa Canal at Mile 11.4, 1949 .....	47
43	Contra Costa Canal at Bella Vista, 1949 .....	48

112. Sacramento River. Water Quality and Biology Section. Miscellaneous reports.

Four reports are contained in this binder dating from 1953 to 1963. All reports are reviewed elsewhere in this literature review.

Also included are lists of 1960 Sacramento River and tributary gaging stations, a list and map of the Sacramento River Water Pollution Survey stations and a tentative proposal outlining the objectives of the Sacramento River Survey.

113. Sacramento River (Kimberly Clark and Miscellaneous). Water Quality and Biology Section. Binder.

This binder has three sections (Kimberly Clark, Miscellaneous, and Miscellaneous Monitoring).

Information for a Kimberly Clark water quality monitoring program is outlined .

A table is presented of Sacramento River sampling stations north of Red Bluff with name, river mileage and significance (i.e., gaging station, State Water Quality Monitoring Program, or Sacramento River Water Pollution Survey).

Several tables are presented including water quality cross sections (both vertical and horizontal showing good mixing), hydraulic characteristics (for flows from 2,000-25,000 cfs), monthly minimum flows, quality analyses for Sacramento River and tributaries, and travel times of the river from Red Bluff to the Feather River (for flows of 2,000-25,000 cfs).

Some of the water quality information presented includes, maximum and minimum temperatures, total dissolved solids, and electrical conductivity for several stations on both the Sacramento River and its tributaries. Most of the information is for 1956 through 1964; however, in some cases dates are missing.

A list of road, railroad, and ferry crossings, major diversions, pump structures and pipe crossings is presented for the Sacramento River (as of 1970) by stream mile.

114. Sacramento River Temperature 1976. Water Quality and Biology Section. Data binder.

Temperature data are presented in tabular form. Time and temperature (°F) are presented for July 22, 1976 from Shasta Dam to Or&d Bend and for August 11, 1976 from Shasta Dam to Red Bluff Diversion Dam. The data show an increase in temperature from 57° F (1340) at Shasta Dam to 67° F (1920) at Ord Bend.

Daily maximum and minimum temperatures are presented from July 22, 1976 to October 4, 1976 for the Sacramento River at Jelly's Ferry, at Woodson Bridge, and at the U. S. Fish and Wildlife fish facility at Red Bluff.

In addition, daily USGS maximum and minimum temperatures from October 1, 1975 to September 30, 1976 at the Bend Bridge are presented.

Maximum/minimum daily temperatures at the USFW spawning channel at Red Bluff are also presented from May 1, 1973 through July 31, 1976.

115. Sacramento River, Temperature, Standards and Monitoring. Water Quality and Biology Section. Data binder.

Under the Monitoring Section of the binder, electrical conductivity, total dissolved solids, nitrate and phosphate maximums, minimums and medians for 1951-1964 are presented. The stations (both main stem and tributaries) were part of the Sacramento River Monitoring Program from Keswick Reservoir to Knights Landing. Daily maximum, minimum and average conductivities for the Sacramento River at Red Bluff for June 1961 to July 1962 are also presented.

116. Sacramento River - Temperature Study 09110-0535, April 1968 to Current. Data binder.

Temperature data are presented as maximum, minimum and median temperatures for various stations in the northern Central Valley. The following stations and dates are included: Sacramento River at Dog Creek (March 28 - October 3, 1962); Deer Creek near Vina (January 1951 - December 1951); Keswick Dam (January 1950 -

February 1964); Sacramento River at ACID pump station (December 1968 - November 1970); Clear Creek near Old Highway 99 (April to mid-October 1968) (July 13 - November 24, 1964 for five stations on Clear Creek); Coleman Fish Hatchery (April - mid-October 1968); Sacramento River at Red Bluff Diversion Dam (November 1966 September 1968); Sacramento River near Vina Bridge (April - December 1968); Sacramento River above Colusa Basin Drain (July through November 1968); Sacramento River below Colusa Basin Drain (April through November 1968). Also includes maximum/minimum electrical conductivities from late June to early September 1968.

Some overall trends are evident during the warm periods. Tributaries had higher temperatures with greater diurnal fluctuations. Downstream stations in the river had warmer temperatures and larger diurnal fluctuations with the exception of the Colusa Basin Drain stations that had very low diurnal fluctuations.

117. Sacramento River (Turbidity, Quality Plotting, Conductivity, State Water Project). Water Quality and Biology Section. Data binder.

Turbidity data for the Sacramento River are plotted against discharge of the river and several streams for several dates (October to May 1958 and 1959, November to February, March, April to May and June 1951 to 1969). Also, data (date, time, flow, and turbidity) for stations are presented in tabular form from 1951 to 1970.

Tabular and graphical representations of turbidity data (1960-1968) for the Sacramento River at Colusa and at Bend are also shown.

Thirty-nine graphs of mineral data are presented for four stations on the Sacramento River (at Bend Bridge, 1955-1960; at Butte City, 1955-1960; at Knights Landing, 1951-1960; and at Boyers Pump, 1960). Some plots include mineral versus discharge and conductivity versus minerals. Conductivity strongly correlated to hardness, bicarbonate, sodium, magnesium and calcium. However, no linear regression analysis is presented.

A tabulation of mean daily conductivity for the Sacramento River at Hamilton City and at Colusa (late June 1970 to early January 1971) is presented.

A time-related plot of conductivity from 1960 through 1969 is presented for several stations (Trinity River, Sacramento River above Colusa Basin Drain, at Keswick, and at Snodgrass Slough, Cache Creek, Putah Creek and Thomes Creek).

Generally the conductivity of the river increases and shows greater fluctuation as it moves downstream. Cache, Putah, and Thomes Creeks had substantially higher conductivities that fluctuated widely.

Some basic water quality data (total dissolved solids, conductivity, nitrate, phosphorus, temperature, mean discharge and turbidity) are also presented for Antelope Creek from 1960 through 1964.

118. Sacramento River Water Pollution - Intensives, Lower Reach. Water Quality and Biology Section. Data binder.

Three intensive diurnal sampling runs were conducted (June 20 to June 24, 1960; August 29 to September 2, 1960; and October 24 to October 28, 1960) on the lower reach of the Sacramento River (Mile 62.6 to 3.9). Raw data for 49 stations are presented by station, date, and time in tabular form. Temperatures and dissolved oxygens (mg/L and percent saturation) are presented for each station along with the maximums, minimums and averages. Five-day biochemical oxygen demand, ABS, orthophosphate and total phosphate values are also presented for certain stations.

119. Sacramento River Water Pollution Study - Intensives, Upper and Middle Reach. Water Quality and Biology Section. Data binder.

Intensive diurnal sampling was conducted twice for several stations on the upper reach (mile 294 to 184) and middle reach (mile 184 to 57) of the Sacramento River. Sampling on the upper reach was conducted from June 6 to June 10, 1960 and October 3 to October 7, 1960, and on the middle reach from October 12 to October 16, 1960 and May 8 to May 12, 1961. The data collected include: time, temperature, dissolved oxygen (mg/L and percent saturation), biochemical oxygen demand, ABS, orthophosphate and total phosphate. The information is presented in tabular form with maximum/minimum averages for each parameter over the period of collection.

120. Sacramento Valley Eastside. Water Quality and Biology Section. Data binder.

A list of water quality stations for eastside streams in Tehama and Butte Counties for 1952 to 1960 is presented. Included in the list are the stream name, location, basin and sampling dates. Most stations were intensively sampled in 1959 and 1960. Other stations had sketchy sampling.

A table including dates, discharge and conductivity for seven stations (State Water Quality Monitoring Program) on five streams (1960-1962) is also presented.

The rest of the binder is divided into separate stations on several streams (Antelope Creek, Battle Creek, Big Chico Creek, Butte Creek, Deer Creek, Mill Creek, and Paynes Creek).

Each station begins with a table/graph showing the maximum and minimum on record and the maximum and minimum of 1961 for several parameters (conductivity, temperature, dissolved oxygen, pH, mineral constituents, etc.). The figure includes a plot of monthly values of conductivity, discharge and boron from late 1958 through

1961. Water quality data ranging from 1952 through 1965 are also presented.

121. Station 87a - Sacramento River at Butte City (USGS). Water Quality and Biology Section. Data binder.

Composite samples over approximately 10-day periods were analyzed for various water quality parameters from January 15, 1958 to June 30, 1963 at this station. The parameters include silica, iron, sodium, potassium, sulfate, chloride, fluorides, dissolved solids, hardness, specific conductance, calcium, magnesium, alkalinity by components, total alkalinity, nitrate, boron, pH, color and sodium absorption ratio. In addition, time of collection, temperatures, and specific conductance were recorded on a daily basis. All the data are presented on lab sheets.

122. Stream Data Associated with Benthic Collections. Water Quality and Biology Section. Data binder.

Date of collection, time, temperature, dissolved oxygen, and pH are given for each benthic collection station. In some cases, estimated flow, electrical conductivity, turbidity and alkalinity are also presented.

Cottonwood Creek drainage data from June 9, 1977 to July 12, 1978 are presented under Section C. Other Sacramento River tributary data are presented under Section S. The data were collected from October 1977 to October 1979. Diurnal data for Elder Creek at Lowry Road are presented for July 18, 1979 to July 20, 1979; August 22, 1979 to August 23, 1979; and October 29, 1979 to October 31, 1979.

123. Surface Water (S-Z). Water Quality and Biology Section. Data binder.

Under the Sacramento River Section, electrical conductivity and turbidity data are presented in tabular form by station, date, and time. The stations are presented in alphabetical order. The data range from the early 1960s to the mid-1970s. However, there are very few complete records.

Similar information is presented for tributaries to the Sacramento River in this binder and other surface water binders.

124. Water Quality Data -Sacramento Valley Westside and Eastside, 1973-74. Water Quality and Biology Section. Data binder.

Samples from thirty-one westside streams were collected in January and February of 1973 (Table C-3). The samples were analyzed for electrical conductivity, pH, turbidity, minerals, metals and nutrients.

In addition, similar information was collected for some eastside streams between

Red Bluff and Chico (Table C-4). These samples were collected in November 1973 and January 1974. Metal analyses were not performed.

Table C-3. Sampling Stations for Westside Streams

1	Smith Creek near Zamora, Interstate 5
2	Oat Creek near Dunnigan
3	Buckeye Creek near Dunnigan, Interstate 5
4	Salt Creek near Arbuckle, Interstate 5
5	North Branch Sand Creek near Arbuckle, Interstate 5
6	Cortina Creek near Williams, Interstate 5
7	Salt Creek near Williams, Interstate 5
8	Freshwater Creek near Williams, Interstate 5
9	Lurline Creek near Williams
10	Stone Corral Creek near Maxwell, Interstate 5
11	Funks Creek near Maxwell
12	Hunters Creek near Maxwell, Interstate 5
13	South Fork Willows Creek near Willows, Interstate 5
14	Wilson Creek near Willows, Interstate 5
15	Walker Creek near Orland, Interstate 5
16	Hambright Creek near Orland, Interstate 5
17	Gay Creek near Orland, Interstate 5
18	Moore Creek near Corning, Interstate 5
19	Sour Grass Creek near Corning, Interstate 5
20	Rice Creek near Corning, Interstate 5
21	Brannin Creek near Corning, Interstate 5
22	Hall Creek near Corning, Interstate 5
23	Burch Creek at Corning, Interstate 5
24	Burch Creek near Corning, Interstate 5
25	Jewett Creek near Corning, Interstate 5
26	North Fork McClure Creek near Corning, Interstate 5
27	Willow Creek near Red Bluff, Interstate 5
28	Elder Creek near Gerber, Highway 99
29	Oat Creek near Red Bluff, Interstate 5
30	Coyote Creek near Red Bluff
31	Dibble Creek near Red Bluff

Table C-4. Sampling Stations for Eastside Streams

C-1	Salt Creek near Red Bluff
C-2	New Creek near Red Bluff

- C-3
- C-4 Dye Creek near Los Molinos
- C-5 Toomes Creek near Vina
- C-6 Singer Creek near Highway 99E
- C-7 Pine Creek near Highway 99E
- C-8 Rock Creek near Highway 99E
- C-9 Mud Creek near Chico at Highway 99E
- C-10 Lindo Channel at Highway 99E
- C-11
- C-12 Little Chico Creek at Highway 99E
- C-13 Commanche Creek at Highway 99E near Chico
- C-14 Little Dry Creek at Highway 99E
- C-15 Dry Creek at Highway 99E near Oroville
- C-16 Gold Run Tributary
- C-17 Cottonwood Creek at Highway 99E near Oroville